CALICE Results

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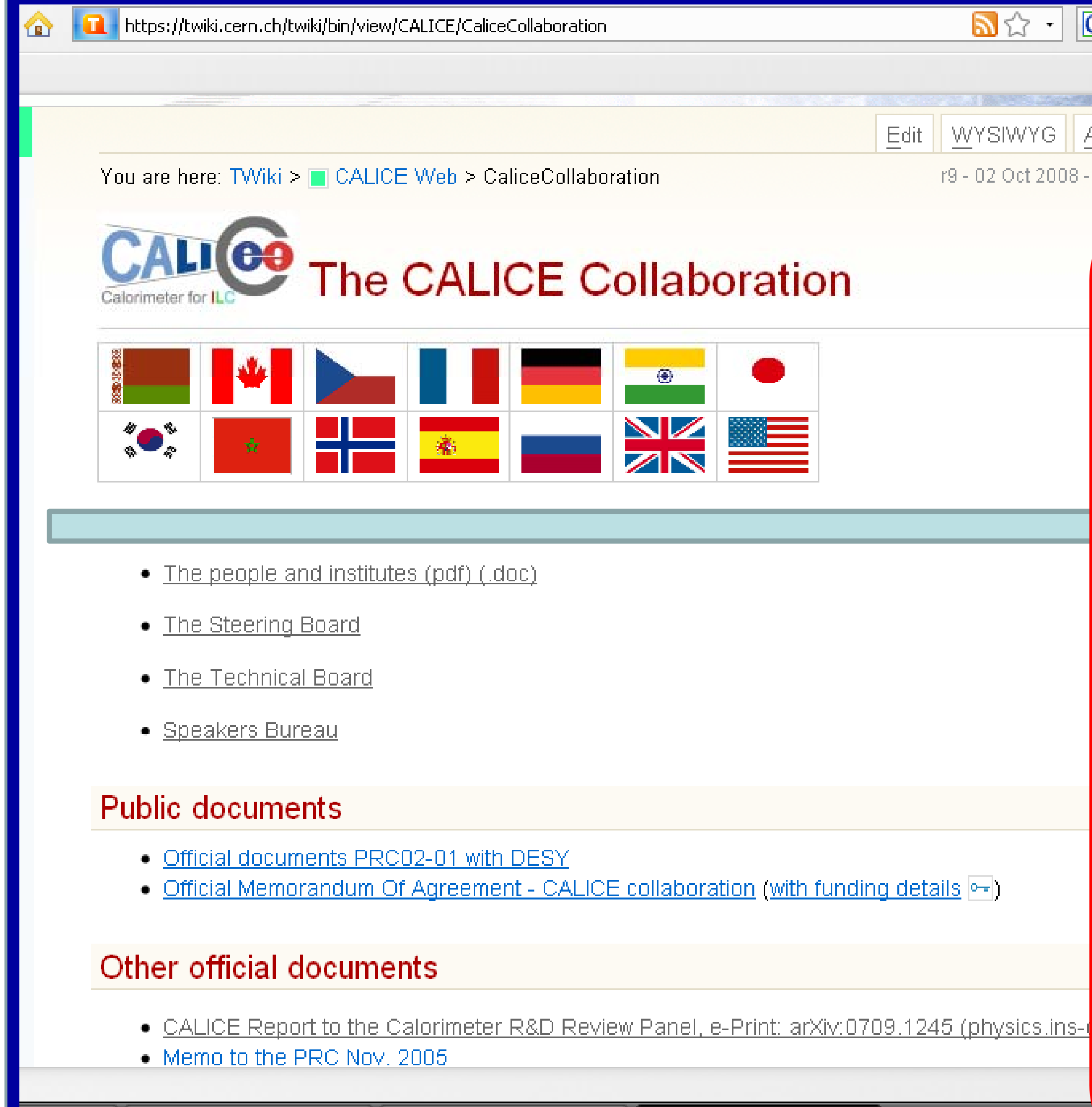
CAlorimeters for the LInear Collider Experiment

Calorimeters optimised for PFA



Calorimeter for ILC

Oct. 2008

293 phys./eng.

51 institutes

14 countries

Design and test calorimeters (ECAL,HCAL) optimised for PFA

Test beam at DESY, CERN and Fermilab

Projects and developments in CALICE

- ECAL Tungsten – silicon
- ECAL Tungsten - scintillator strips
- ECAL Tungsten – MAPS (DECAL)

- HCAL scintillator Tiles
- HCAL digital RPC or GEM
- HCAL semidigital gas device (SDGHcal)
- TCMT : Scintillator/SiPM muon tagger

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- VFE at high level of integration (an ATLAS readout board in a single chip)
- DAQ new generation (FPGA's and commercial board)
- GEANT4 simulation for prototype as well as for LOI detector model
- Analysis of the Test beam .i.e. Hadronic shower model tuning

Our goal is to understand our devices… at such a level
That we can be ready for construction when needed
(our goal 2012)

Projects in 3 steps

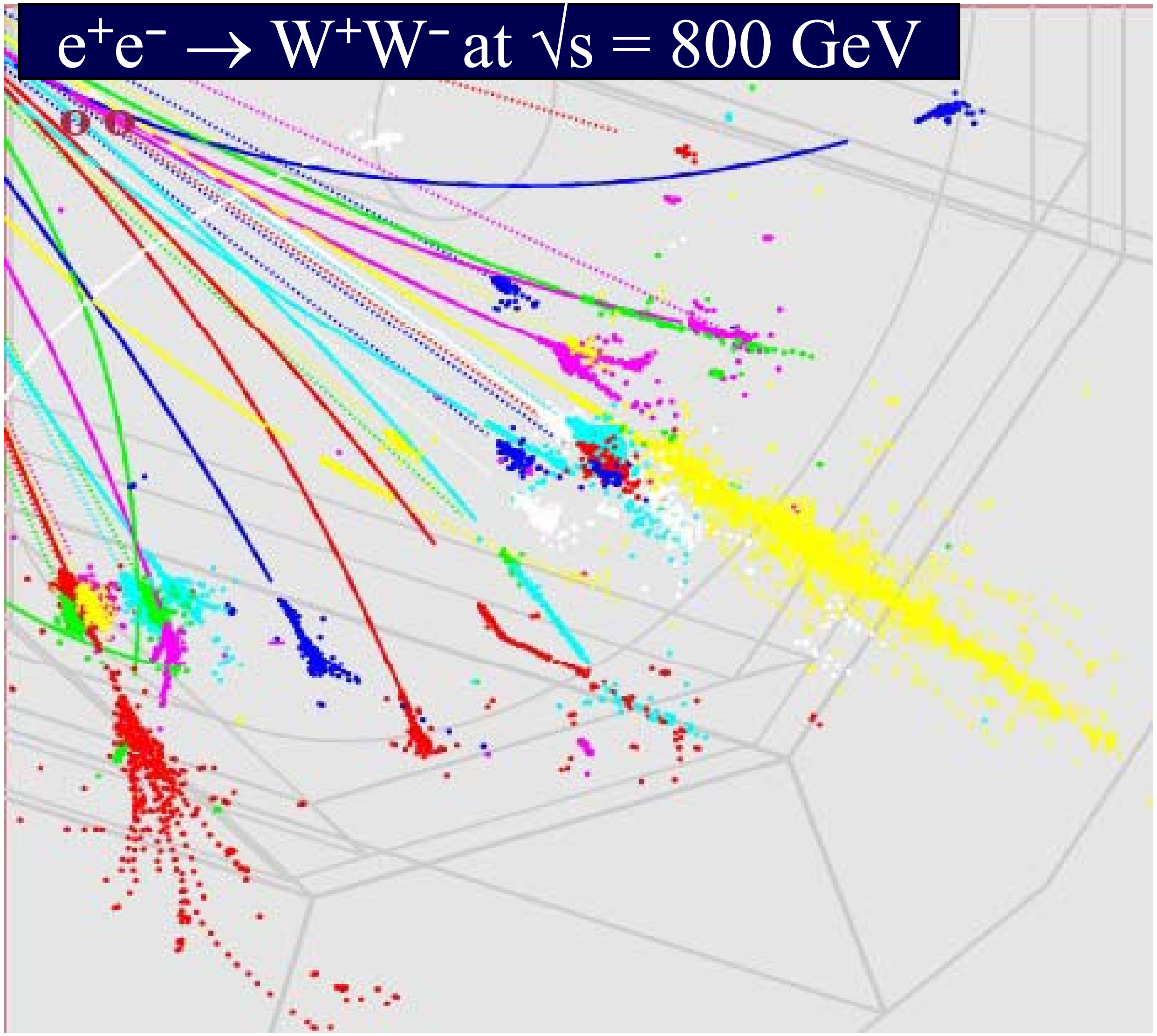
1) First generation of ECAL and HCAL
(understanding the problems)

2) Second generation of ECAL, HCAL, much closer to the final detector
(solving the problems and goes to the right scale)

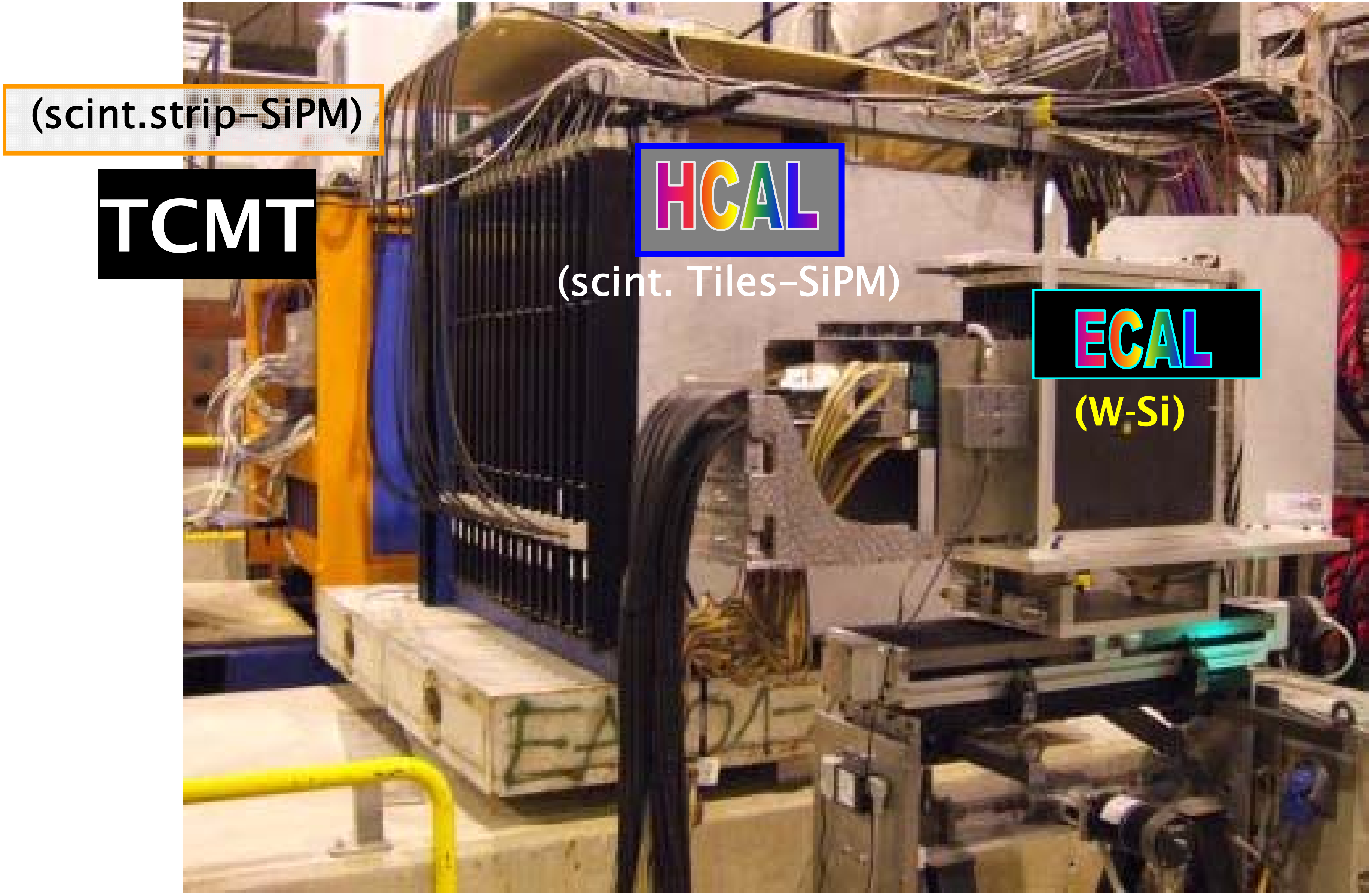
From 1) and 2) , must lead to

3) Construction and test of a module zero (After LC construction decision)
(a typical module of the calorimeter)

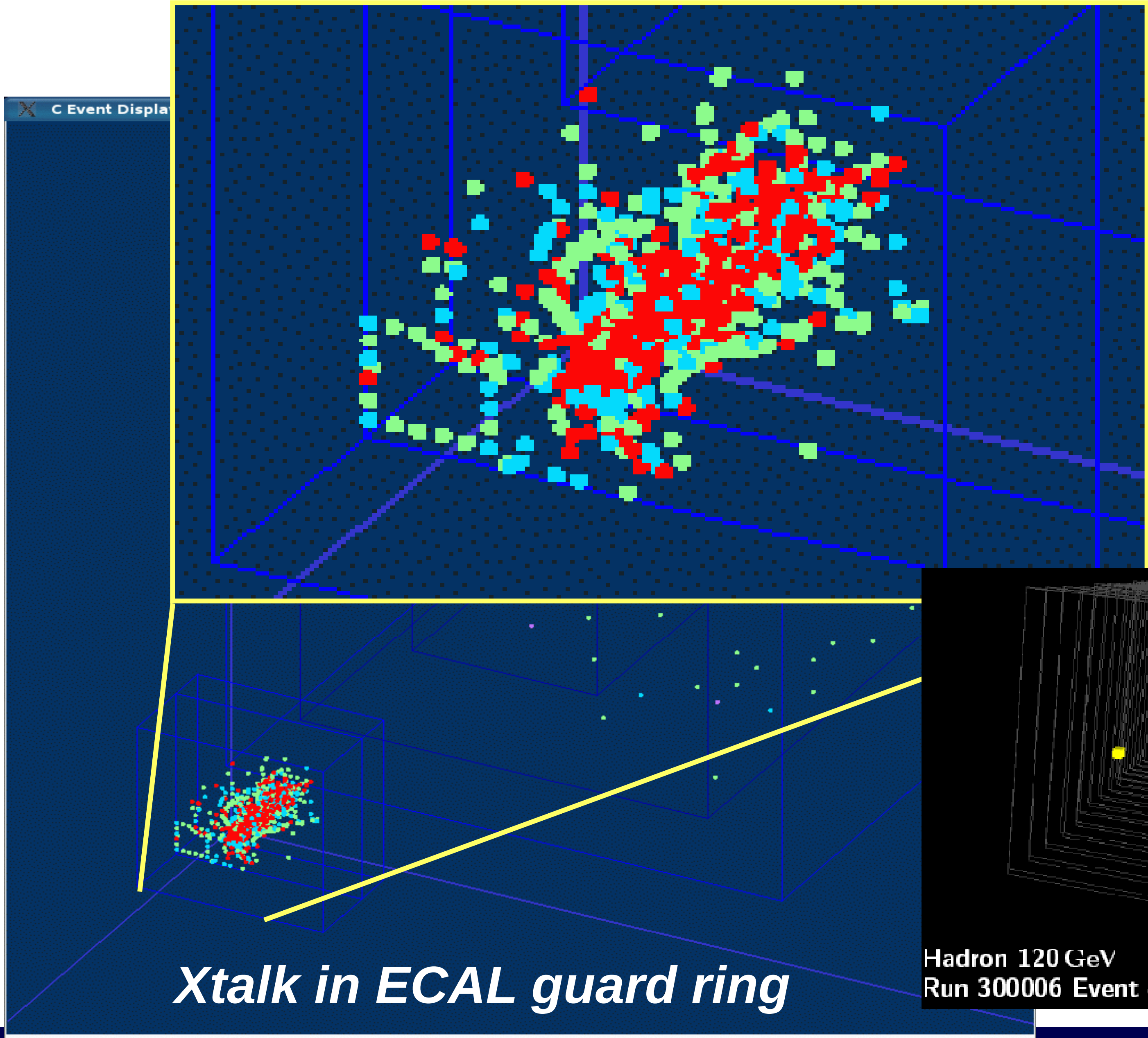
From dream



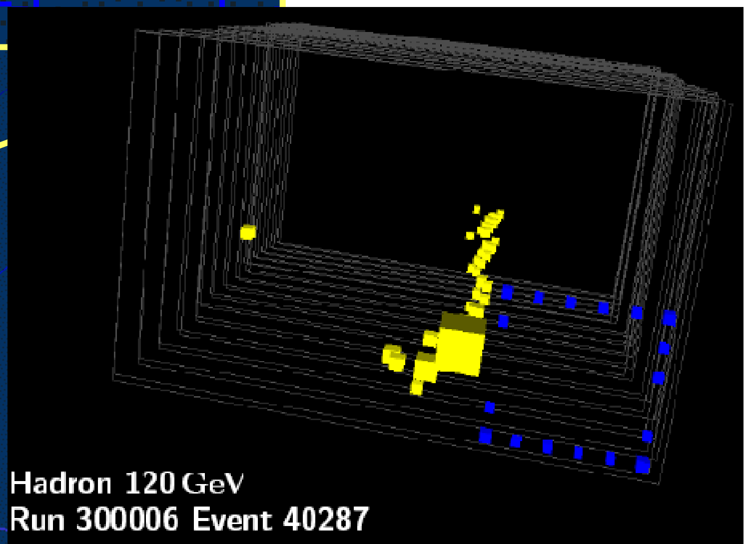
To real STEP 1



To reality ....



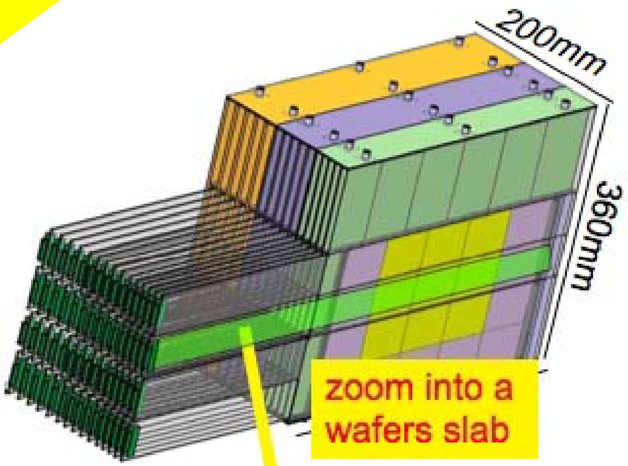
ieee paper
by Remi Cornat
on the study
of the effect

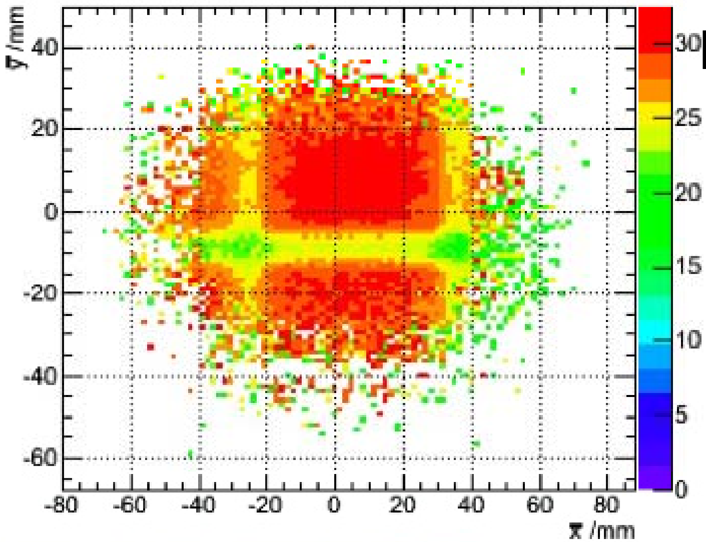


Lessons from Step 1 SiW ECAL

Ecal Correction of Energy Deposition

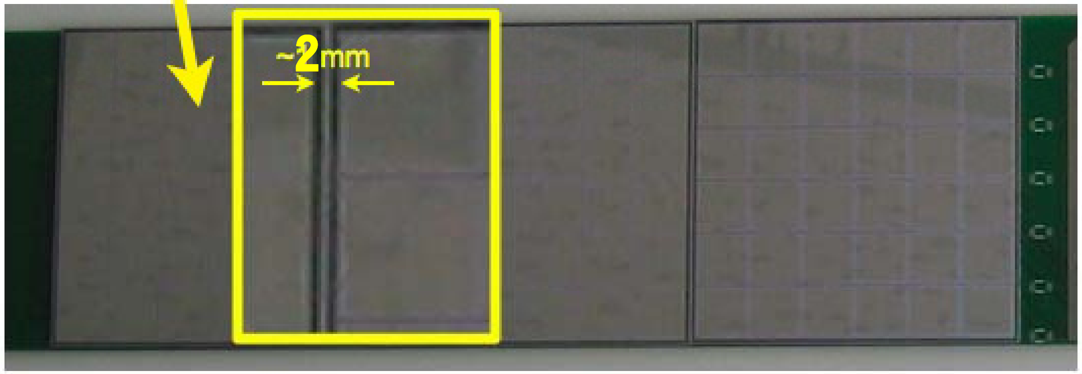
Dips in energy measurement by inter wafer gaps (needed for isolation)





E/GeV

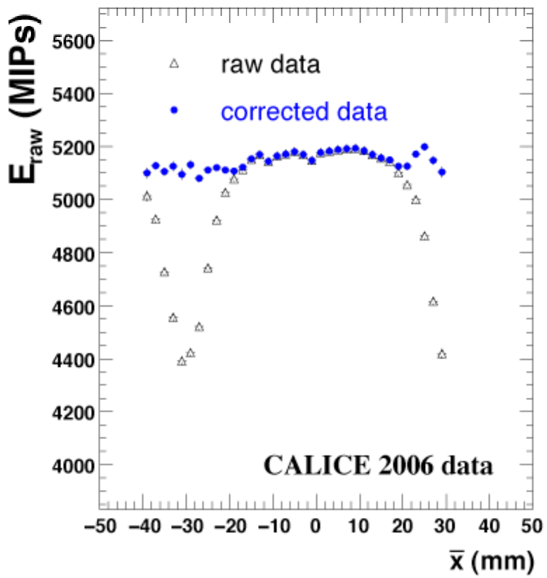
Absolute calibration by comparing E_{dep} on MIP level with beam energy

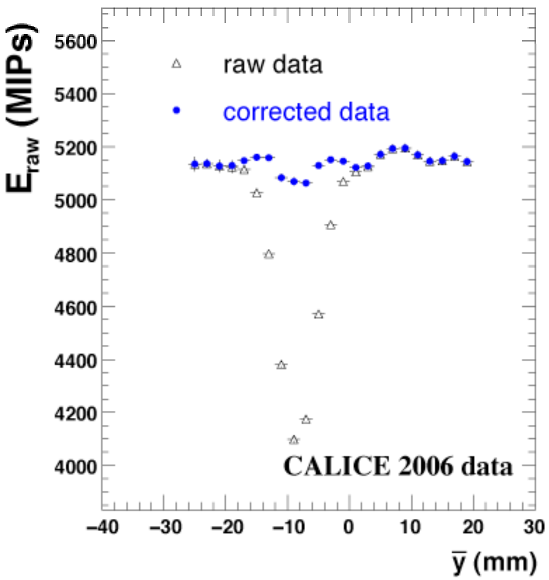


Need to take geometrical acceptance into account in analysis

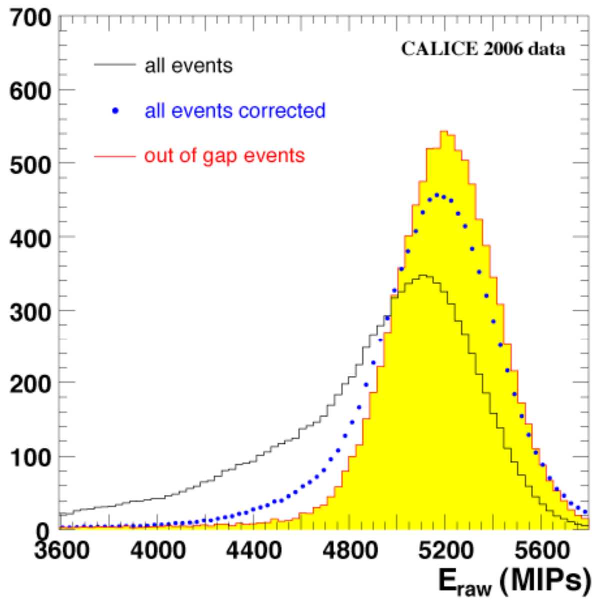
It is in ILD GEANT4 simulation

Correction of Energy Deposition I – Acceptance Correction





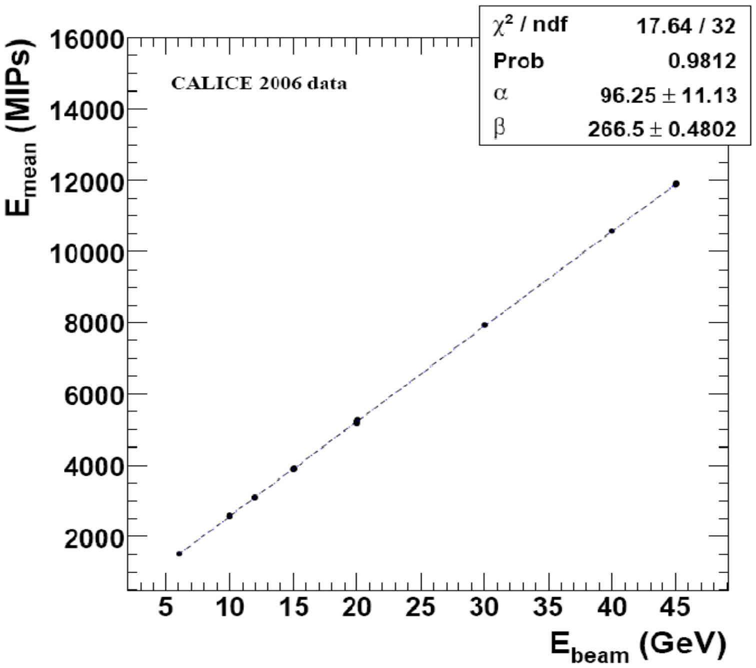
Restoring homogeneous Response with correction function

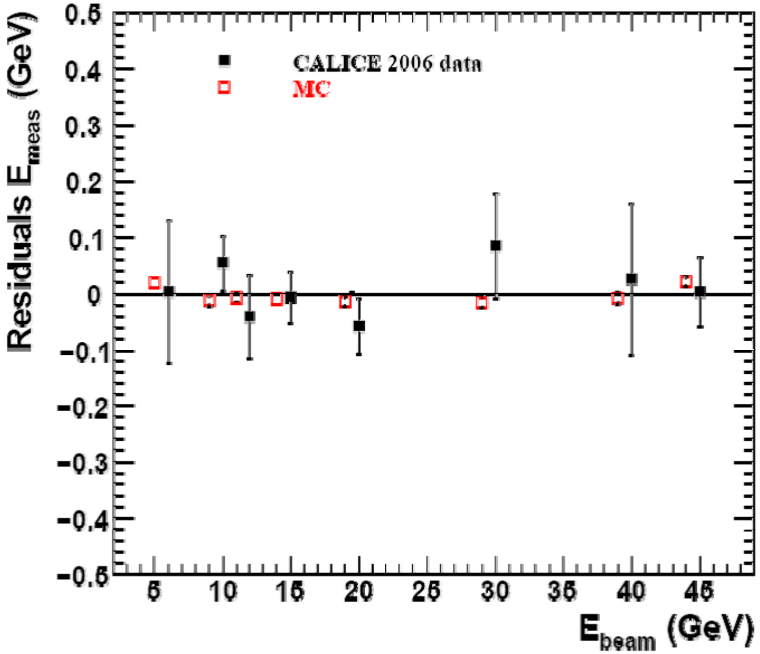


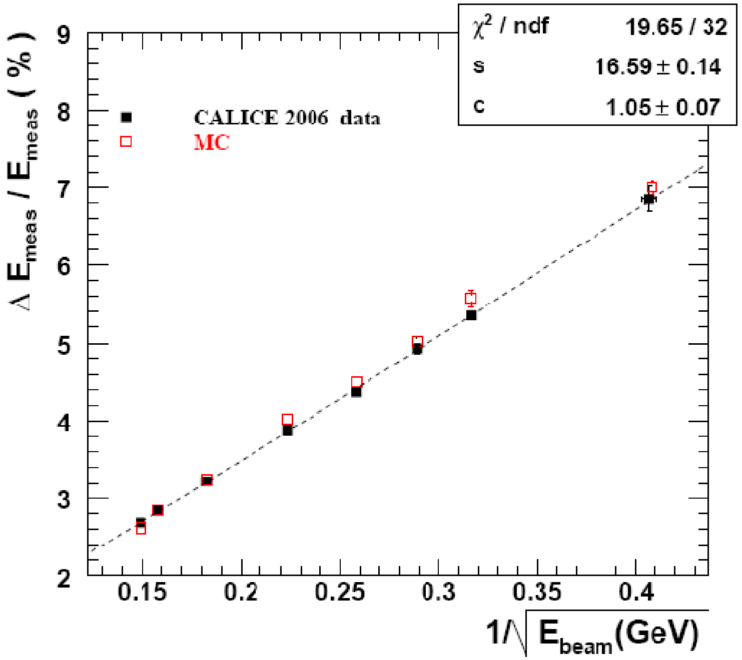
Energy loss due to acceptance limits not fully recovered

Important issue for future R&D

Requires close collaboration between CALICE and SiWafer Suppliers

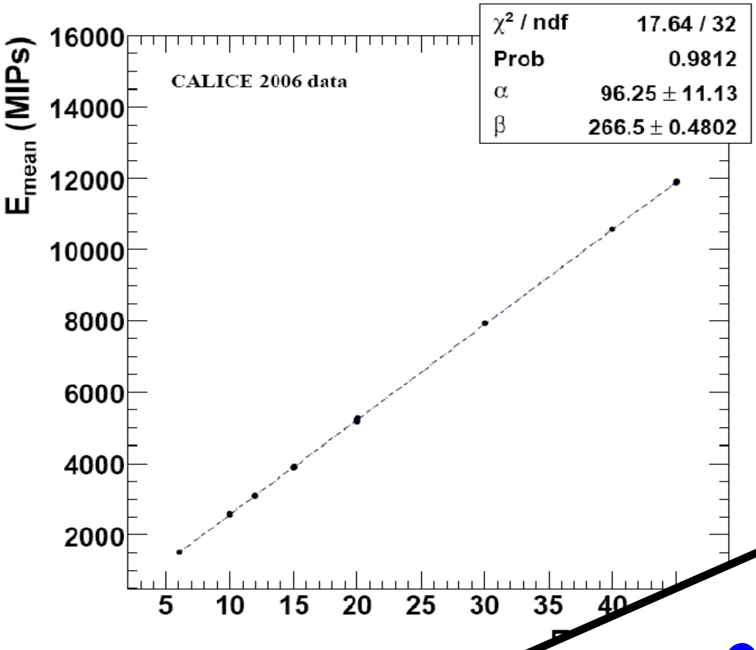


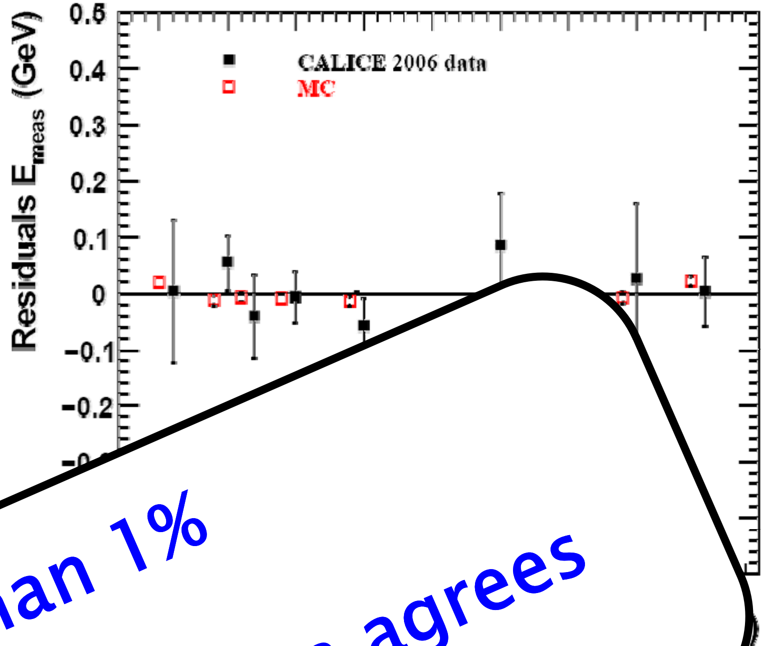


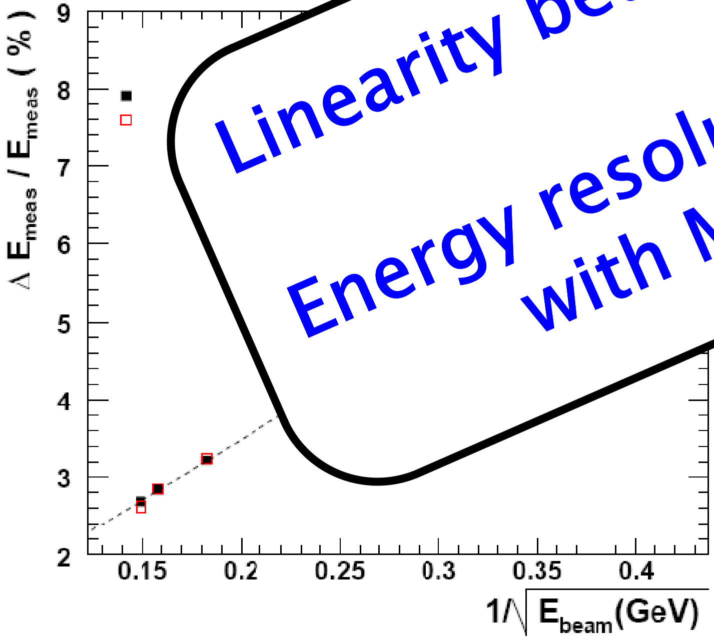


$$\frac{\Delta E_{meas}}{E_{meas}} = \left(\frac{16.6 \pm 0.1}{\sqrt{E(GeV)}} \oplus 1.1 \pm 0.1 \right) \%$$

$$\frac{\Delta E_{meas}}{E_{meas}} = \left(\frac{17.3 \pm 0.1}{\sqrt{E(GeV)}} \oplus 0.5 \pm 0.1 \right) \%$$







Linearity better than 1%

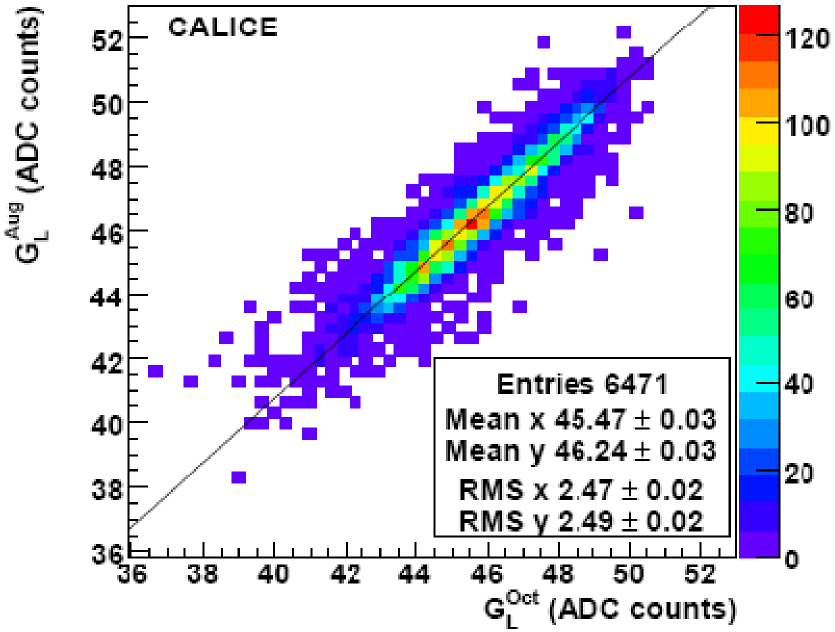
Energy resolution on data agrees with MC within 5%

$$\ldots = \left(\frac{\ldots 6.6 \pm 0.1}{\sqrt{E(GeV)}} \oplus 1.1 \pm 0.1\right)\%$$

$$\frac{\Delta E_{meas}}{E_{meas}} = \left(\frac{17.3 \pm 0.1}{\sqrt{E(GeV)}} \oplus 0.5 \pm 0.1\right)\%$$

From Step 1 Ecal SiW

As expected, a PIN diode silicon detector is STABLE



–SiW Tungsten Ecal with up to 9400 cells operated successfully during testbeam campaigns 2006 to 2008

– Stable operation
  uniform response to MIPs, robust calibration
  only 1.4/mill dead cells

– Shows direction for future R&D
- Wafer Guard Ring effects
- Effect of negative Xtalk on adjacent cells
- Importance of dead (or grey) zone

– Energy resolution and Linearity well described by MC
  Linearity O(1%)
  Resolution $(17\%/\sqrt{E} + 1)\%$

Ready to proceed to step 2

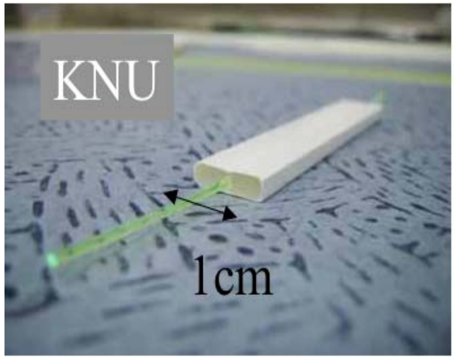
Review of imperfections in the STEP-1 ECAL W-Si proto is in the talk of Marcel Reinhard

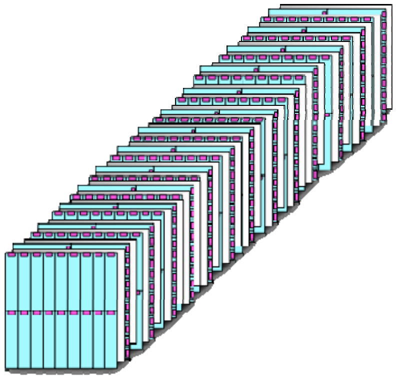
Tungsten –Scintillator ECAL

Calorimeter for ILC

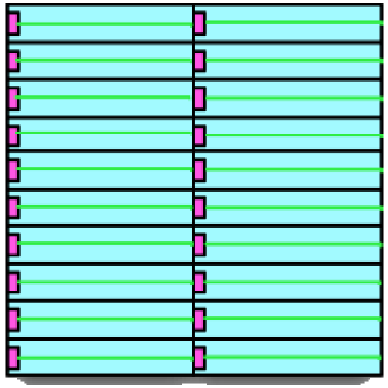
First, a test prototype in test beam at DESY in 2007

Kyunpook N.U





9cm



9cm

KOBE UNIVERSITY

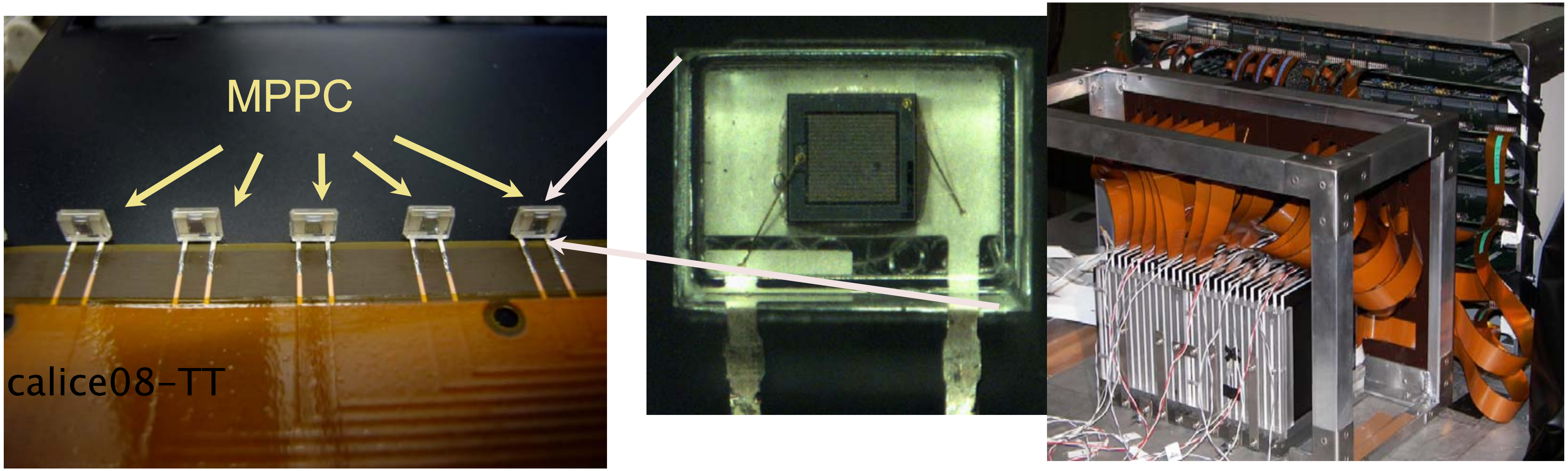
SHINSHU UNIVERSITY

Now , the STEP1 prototype is in test beam at FNAL-MTBF

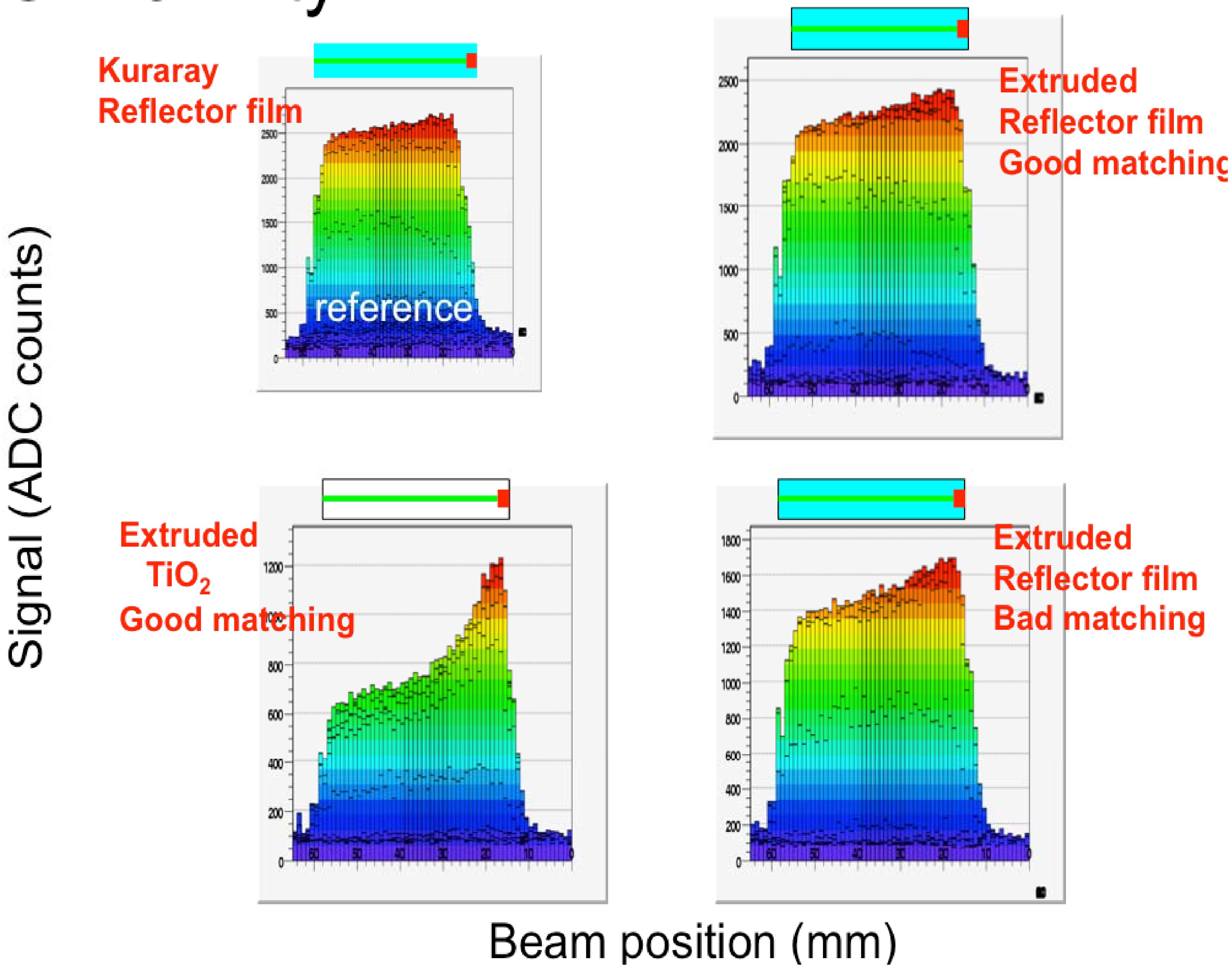
First test prototype

- 9x2 strips / layer x 26 (468ch)
- 1cm x 4.5cm x 0.3cm strip
- fibre in a hole
- without fibre
- MPPC read out

Test beam@DESY 2007



Uniformity

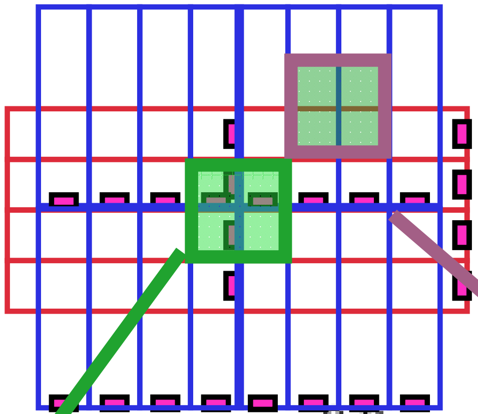


Kuraray
Reflector film
reference
Extruded
Reflector film
Good matching
Extruded
TiO2
Good matching
Extruded
Reflector film
Bad matching
Signal (ADC counts)
Beam position (mm)

energy resolution

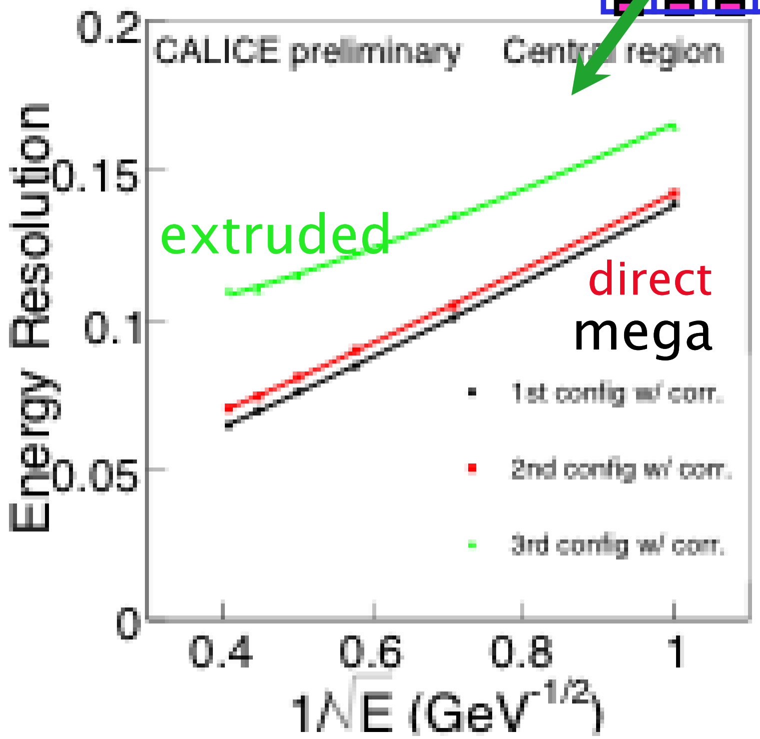
detector center
is a singular point

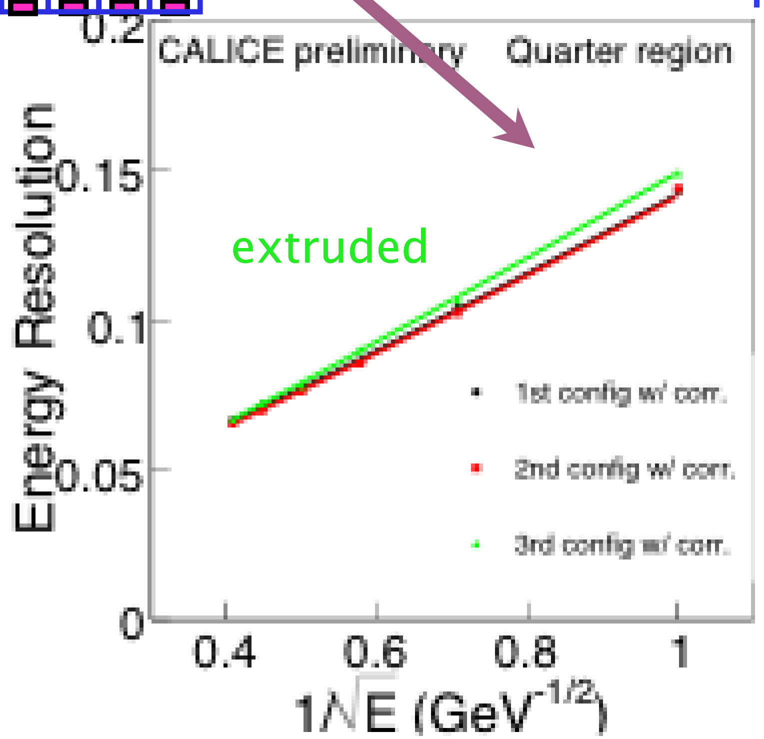
without saturation
correction



$$\frac{13\%}{\sqrt{E}} \oplus 3\ \%$$

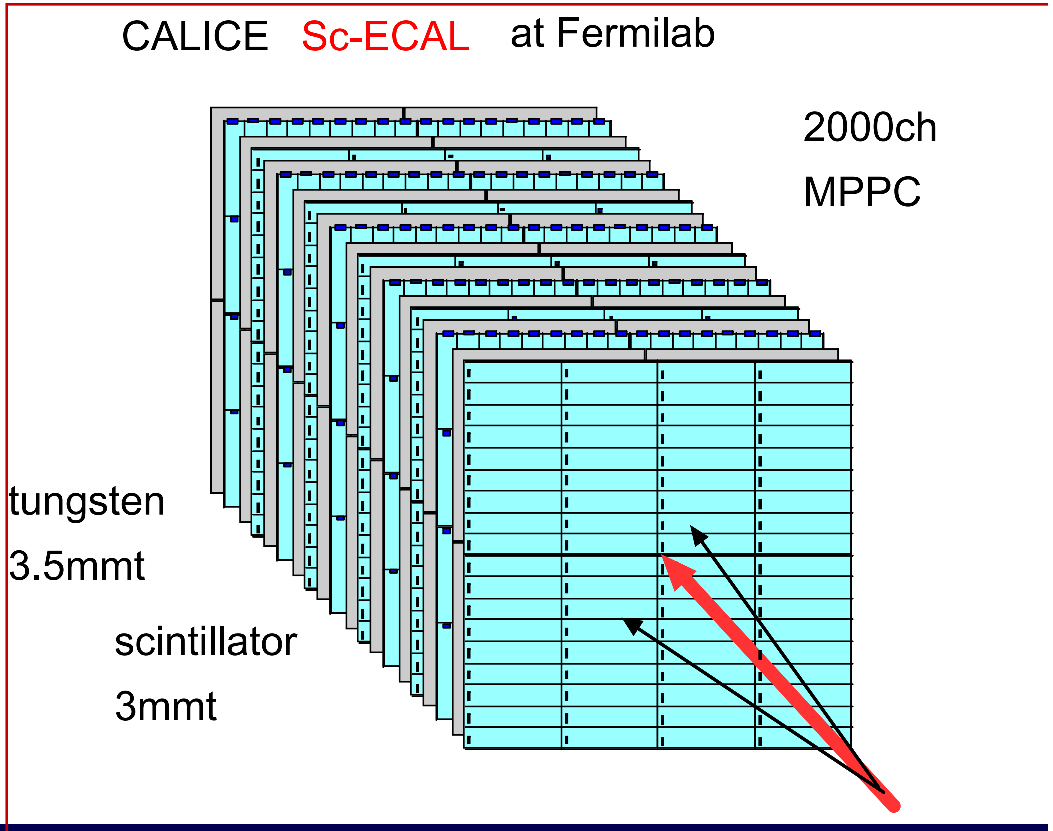
shower
leakage





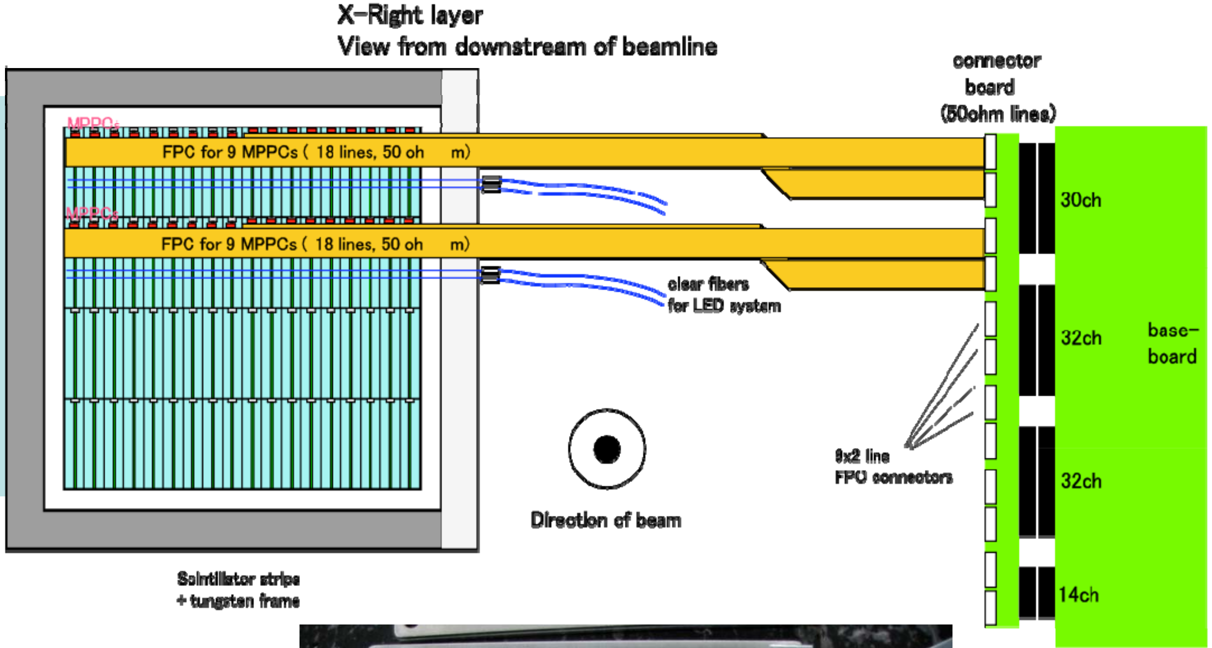
STEP 1 prototype scint-ecal

- x4 bigger ECAL than DESY : prototype
- 18cm x 18cm x 30 layers (2160ch)
- extruded scintillators w/o TiO2 shield
  - precise positioning of MPPC
- monitoring system
- moved mid August

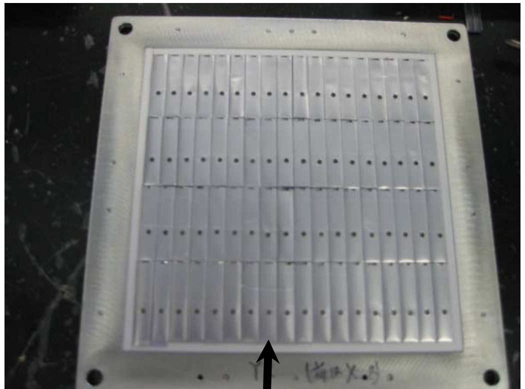


STEP 1 prototype scint-ecal

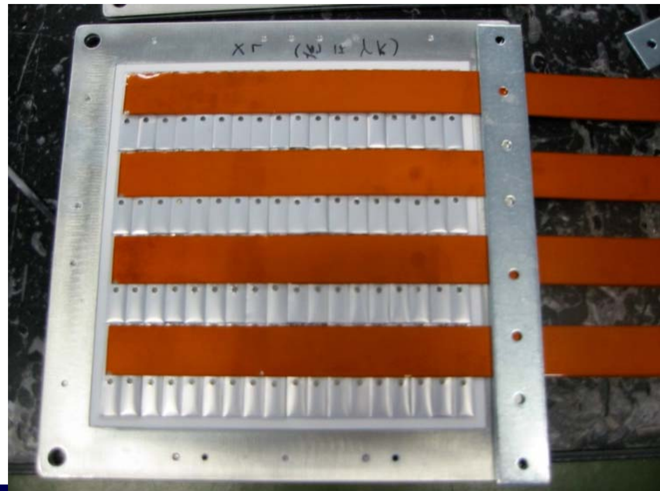
W 3.5mm scint. 3mm
18 x 4 lows



tungsten



scintillator strip



Step 1 Scintillator ECAL Test beam

- September run of the CALICE beam test has been successfully done at FNAL-MTBF *(Thanks to FNAL for all the help)*

- We have collected various data to evaluate fundamental performance of the Scintillator-ECAL + Analog HCAL.

- First trial of the π^0 reconstruction with ScECAL is in good shape.

- Extensive Analysis is currently underway. And the FNAL TB will deliver his verdict

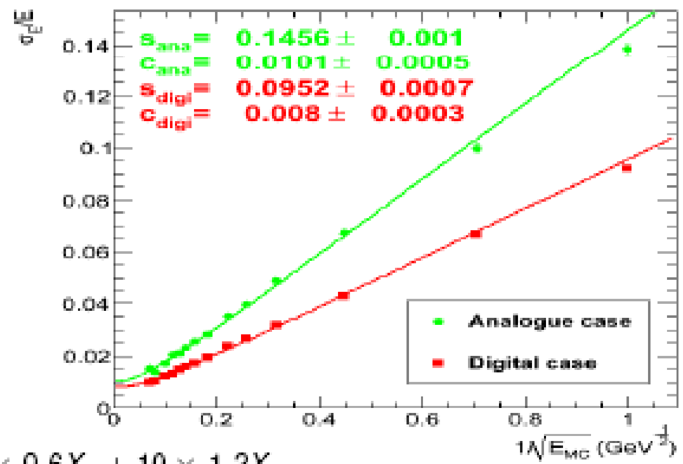
MAPS ECAL

Ultimate granular ECAL

Digital vs Analogue: motivations

	Analogue	Digital
Measure	$E_{deposited} \propto N_{Charged\ particles} \propto E_{incident}$	$N_{Charged\ particles} \propto E_{incident}$
Fluctuations	statistical, angle of incidence, velocity and Landau spread	statistical
Ideal resolution	$\simeq \frac{0.15}{\sqrt{E}}$ for ILC-like ECAL	$\simeq \frac{0.10}{\sqrt{E}}$ for ILC-like ECAL
Realistic effects	noise, dead areas	Charge diffusion, noise, dead areas, counting particle
Impact	Expected small	under study/never measured

- Can we measure the number of charged particles directly?
- Can we get anywhere near the ideal resolution for the digital case?



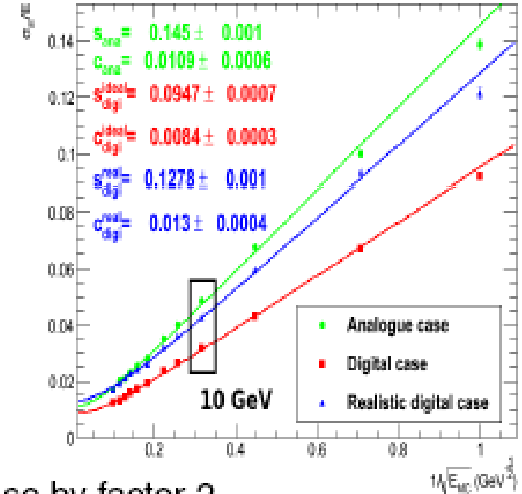
$20 \times 0.6X_0 + 10 \times 1.2X_0$

MAPS ECAL

Ultimate granular ECAL

Resolution vs Energy

- Now have concrete noise values and measured charge diffusion
- Current extrapolation to "real" detector shows significant degradation of ideal DECAL resolution, but still less than ideal analogue resolution.
- 35% increase in error.
- Number of pixels hit not trivially related to number of charged tracks



Degradation arises from

- Noise hits : ≃ 5% degradation when increasing noise by factor 2.
- Dead area : ≃ 6% degradation + ≃ 2% if adding sensor edges effect.
- Charge diffusion to neighbouring pixels : after clustering, ≃ 5% degradation.
- Particles crossing pixels boundaries and sharing pixels : ≃ 20% degradation.

Critical missing measurement: behaviour in a shower.

- Need real data samples of showers at various depths in tungsten
- Compare with Geant4 simulation at 50 μm granularity
- Check critical issues of charged particle separation and keV photon flux

And the HCAL projects ?

- ECAL Tungsten – silicon
- ECAL Tungsten - scintillator strips
- ECAL Tungsten - MAPS

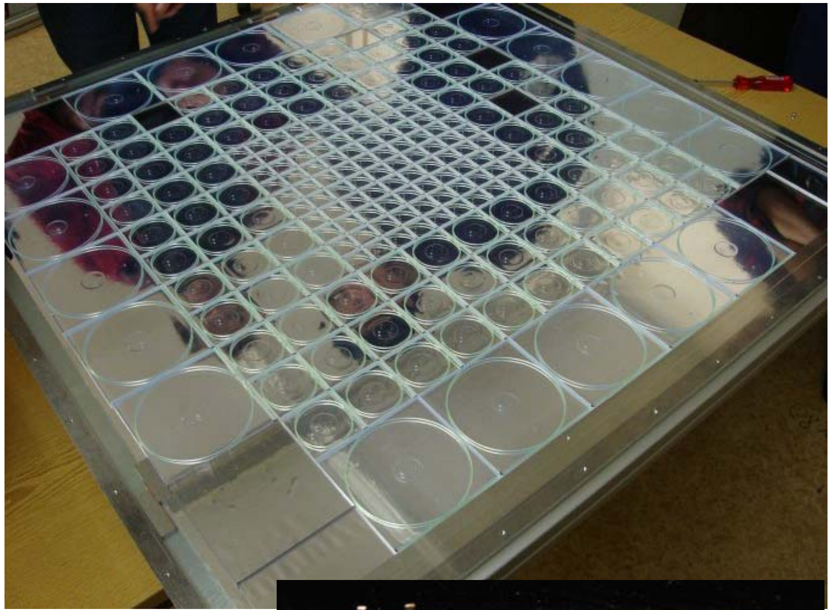
- HCAL scintillator Tiles
- HCAL digital RPC or GEM
- HCAL semidigital gas device (SDGHcal)
- TCMT : Scintillator/SiPM muon tagger

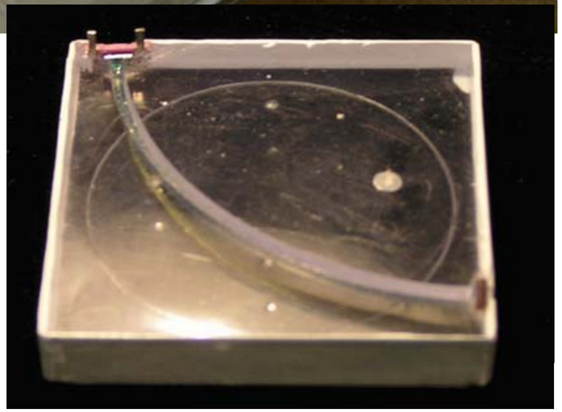
&

- VFE at high level of integration (an ATLAS readout board in a single chip)
- DAQ new generation (FPGA's and commercial board)
- GEANT4 simulation for prototype as well as for LOI detector model
- Analysis of the Test beam .i.e. Hadronic shower model tuning

Step 1 Scintillator Tile HCAL

- Novel multi-pixel Geiger mode photo-diodes (SiPMs)
- 3x3 cm^2 tiles in the centre
- 2 cm steel absorber plates
- 38 layers, 7608 channels



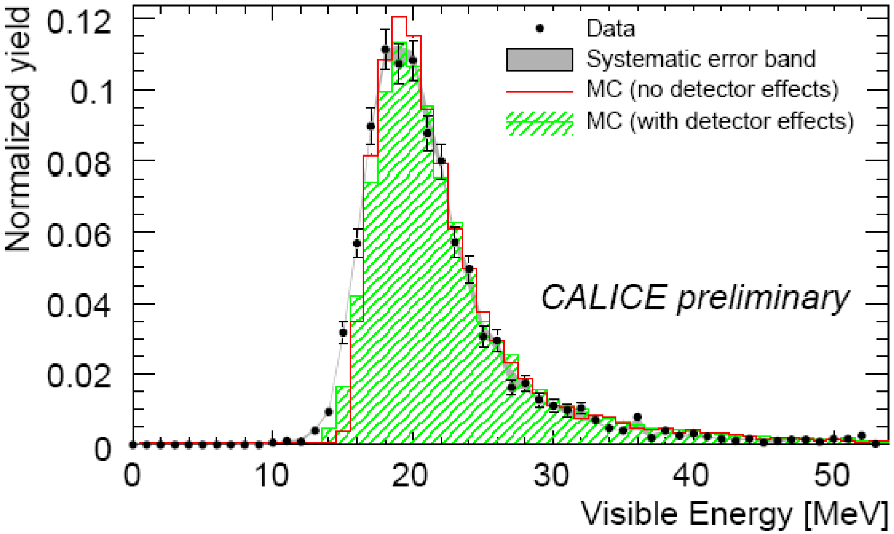


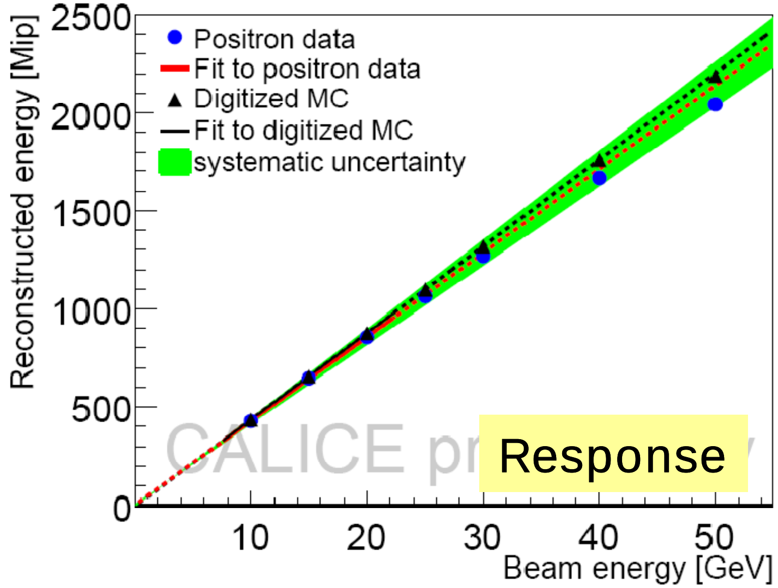
Test beam results:

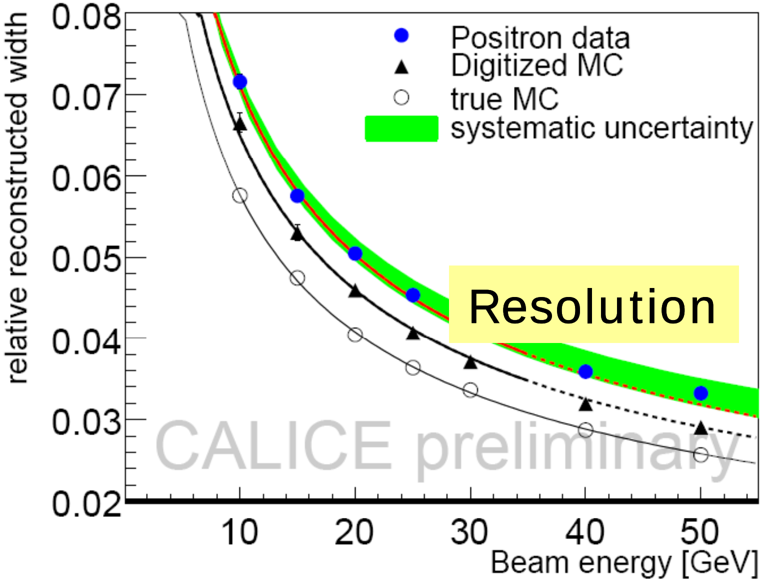
- Stability (98% working channels)
- Noise: occupancy 10^{-3}
- Calibration procedures
- Validation with em showers
- Hadronic showers
- Topological analyses

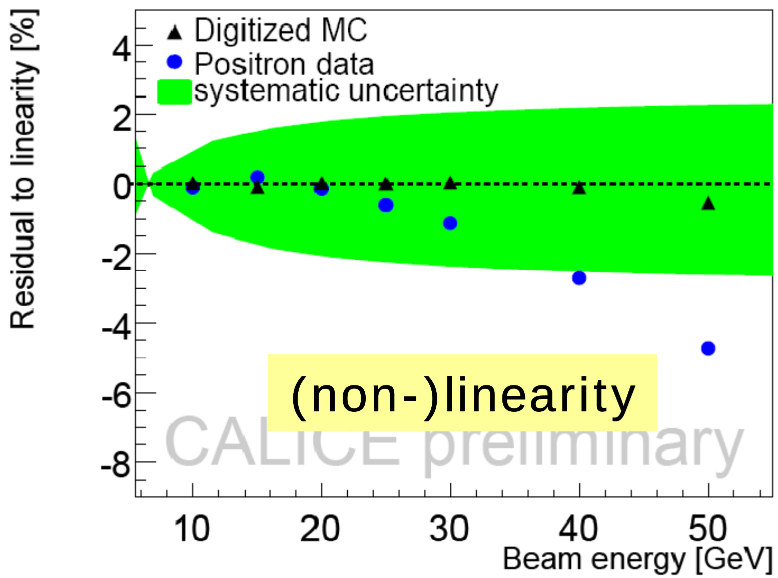
Yes, we understand our detector

μ and e response of AHCAL

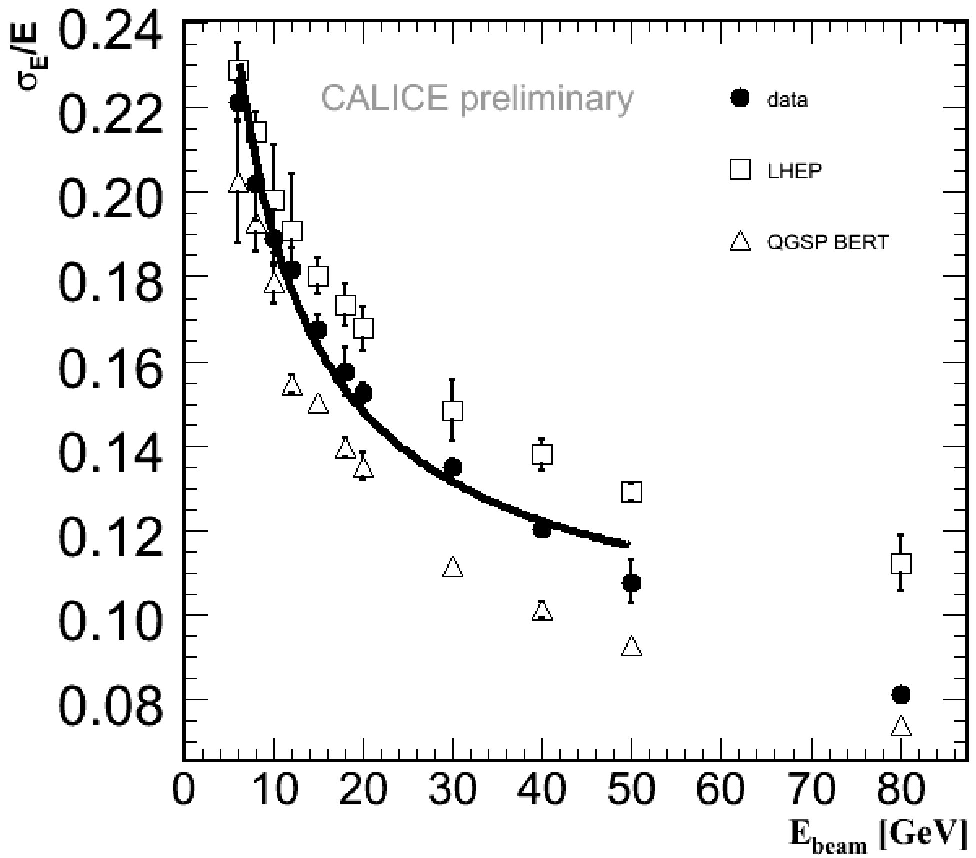


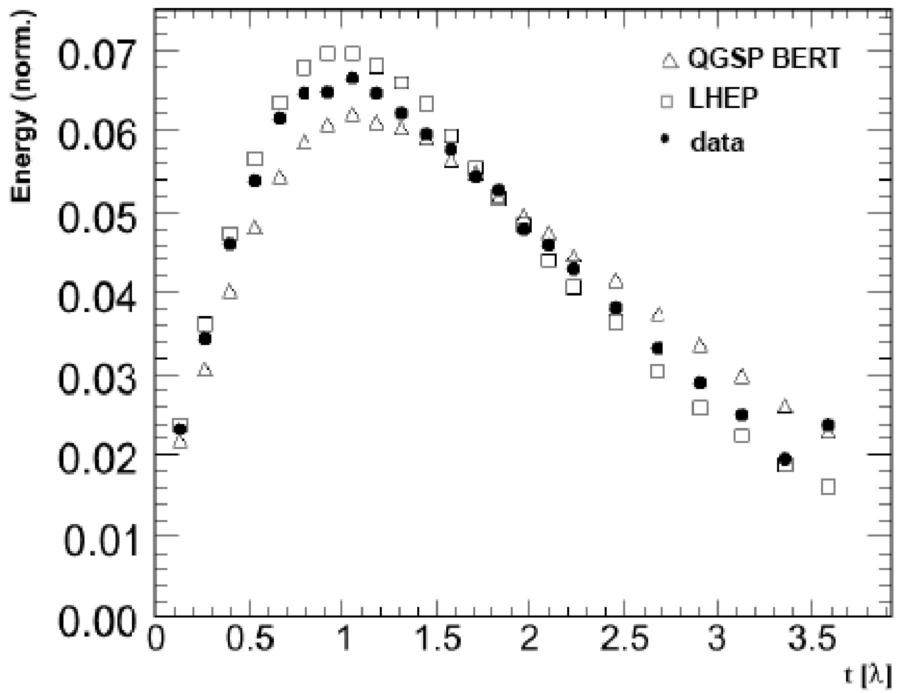






Hadrons: resolution and long. profile





AHCAL test beam conclusions

- SiPM technology works fine
- SiPM response can be monitored (non-linearity, temperature dependence)

- Calibration with MIP stubs in hadron showers possible
- Detector understanding: precision for tests of shower model

Analysis started on

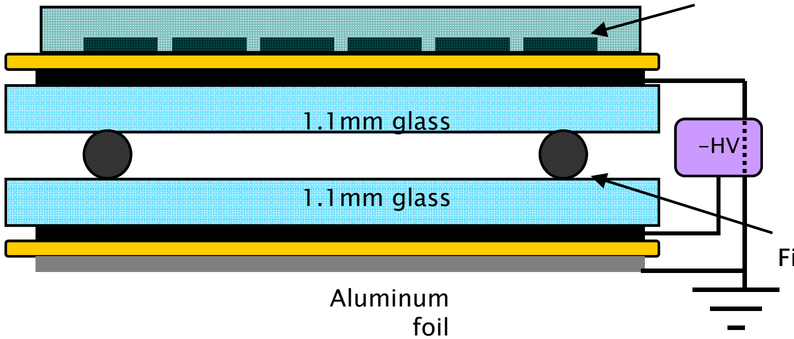
- Study on global properties of hadronic response (within expectations)
- PFLOW performance: two particle separation can be verified with test beam data

- SOFTWARE COMPENSATION looks useable and improve resolution

  (from the level of signal but also from the geometry of the shower)

PFA calorimeter is also a compensating calorimeter !!

Imaging Hadron Calorimeter



Collaborative effort of

Argonne, Boston University, FNAL, University of Iowa

Sandwich calorimeter with

Absorber – 20 mm thick steel plates
Active elements – Resistive Plate Chambers (RPCs)

Based on simple design
Robust and reliable (yes!)
Large signals
Can be made to be thin
Allows for segmented readout

Readout

Longitudinally – every layer individually
Laterally – 1 x 1 cm^2 pads

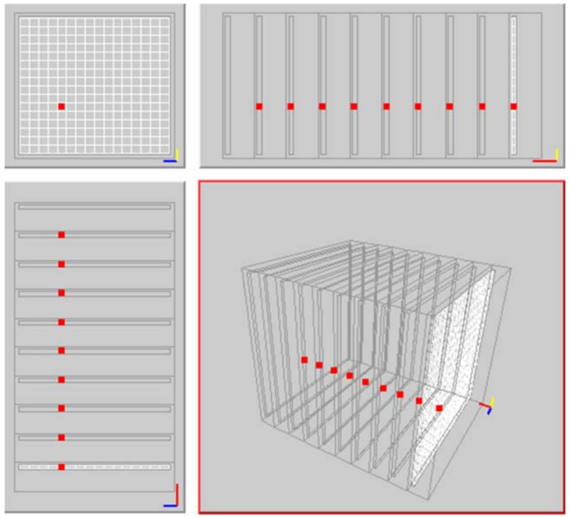
Resolution

1 bit/pad

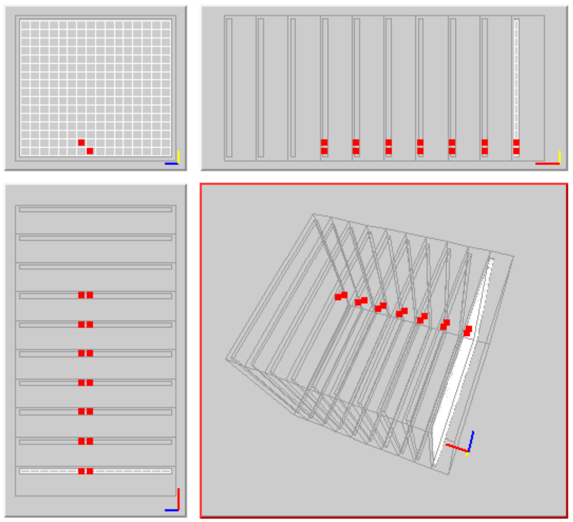
Digital Hadron Calorimeter

A few nice events from the testbeam….

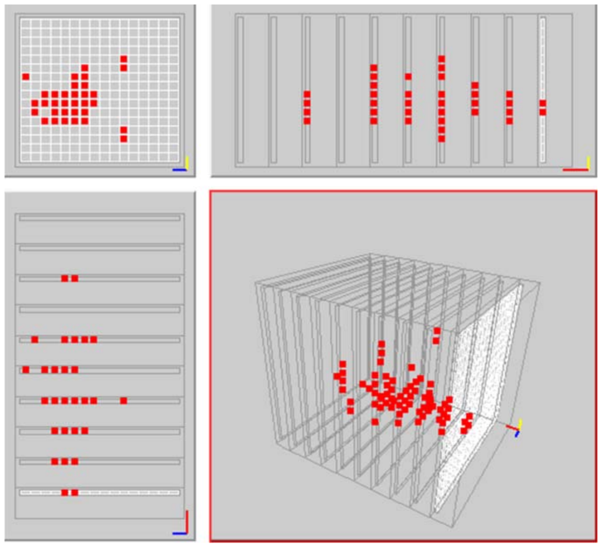
A perfect μ

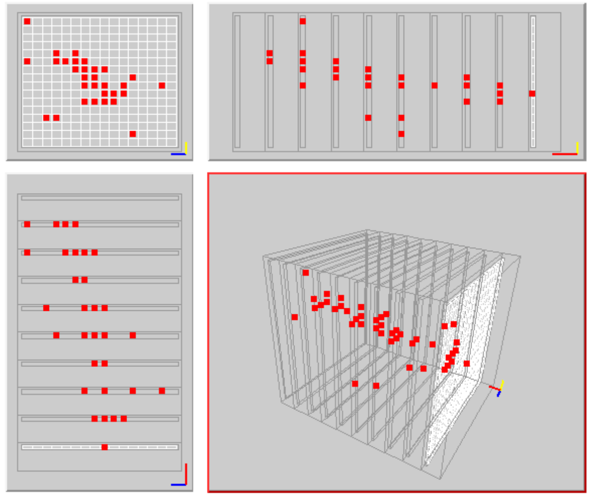


2 perfect μ's

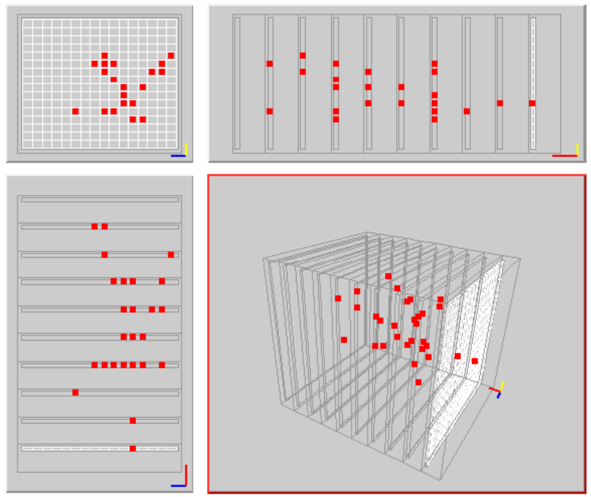


A e^+ shower





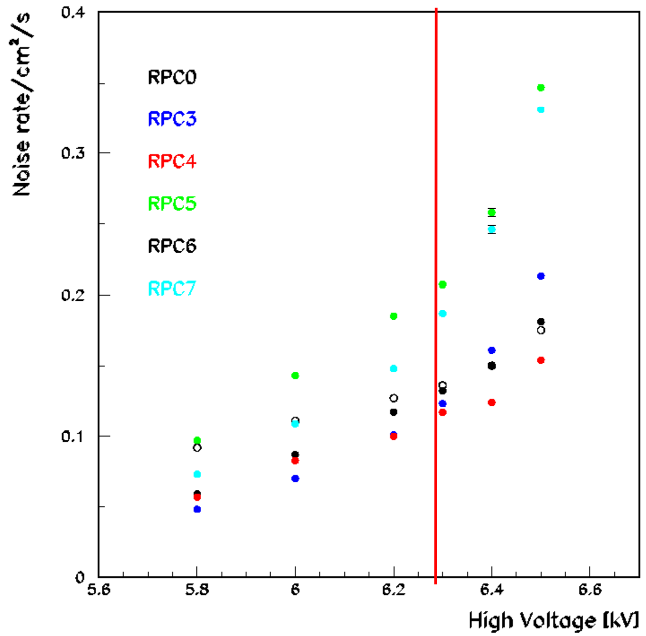
π^+ showers



DHCAL

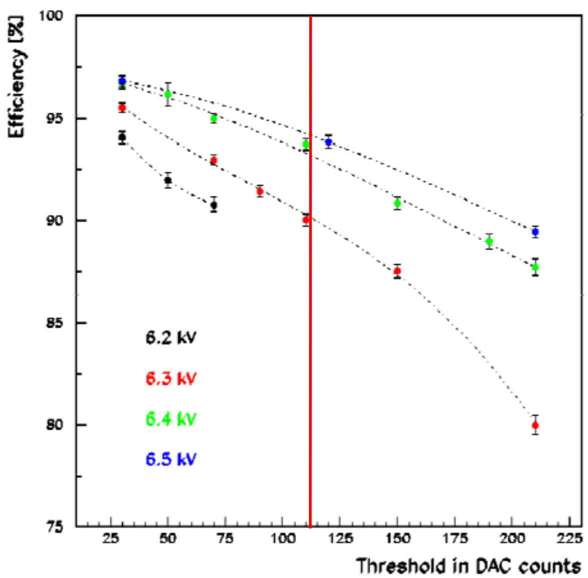
Measurements of Noise in RPCs

Use self-triggered mode of readout system
At default setting
0.1 – 0.2 Hz/cm^2 (extremely low!)



Measurements with Muons

Measurement of MIP detection efficiency and pad multiplicity as function of High Voltage and Threshold

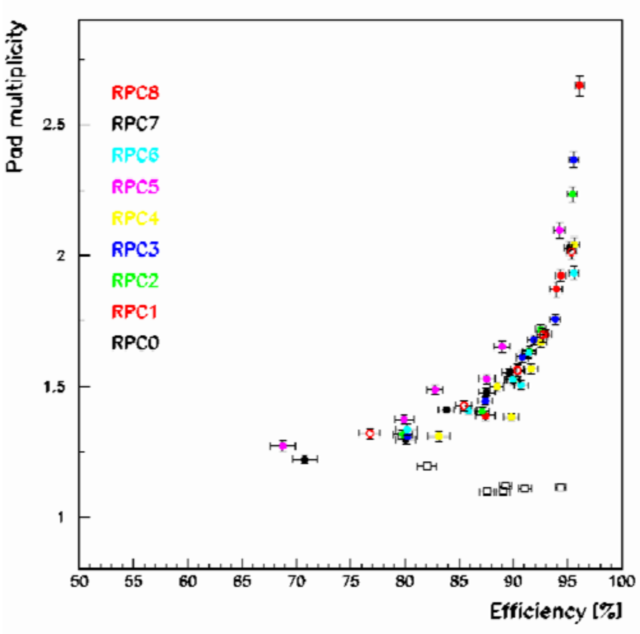


Chose as default operating point

HV = 6.3 kV, THR = 110

$\varepsilon^{MIP} \sim 90\%$

$\mu^{MIP} \sim 1.5$



what have we learned so far?

Thanks to FNAL-MTBF

- **From detailed measurements with RPCs**
  RPCs fulfill the requirements for a digital hadron calorimeter
    High MIP detection efficiency
    Low noise
    Simple design
    Cheap

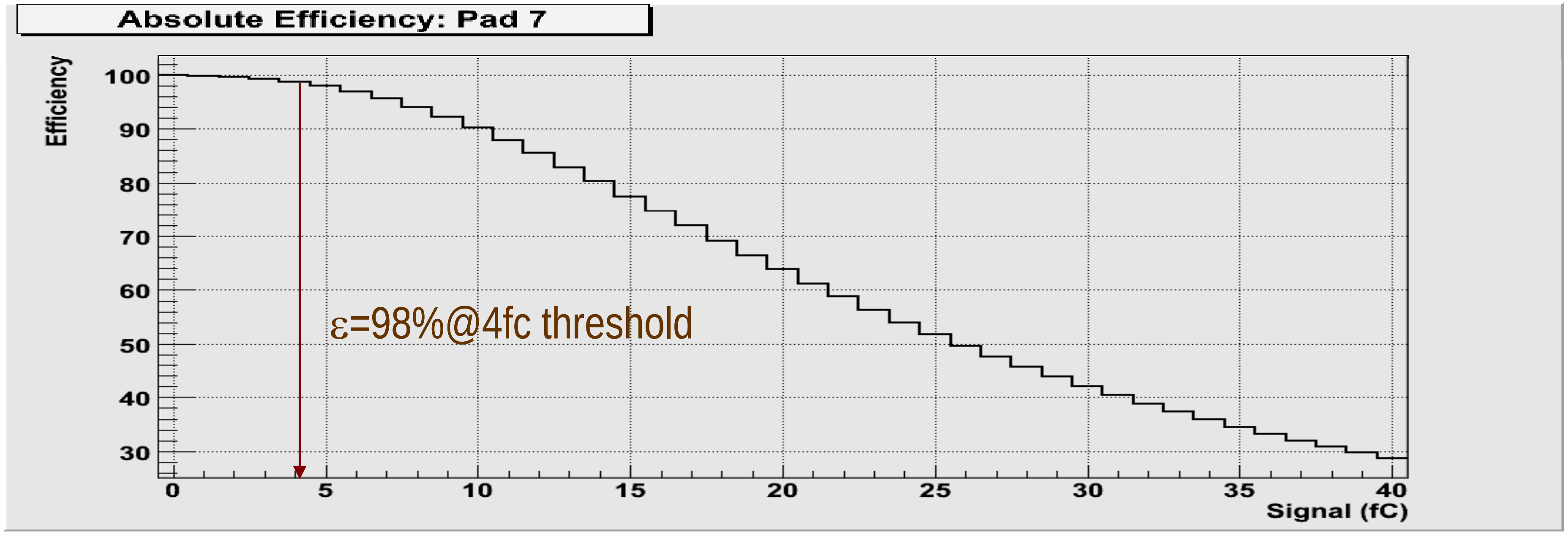
- **From beam tests with Vertical Slice Test**
  Our technical approach works!
  Calorimeter can be calibrated with muons (or charged particle segments)
  Positron response as expected
  Positron shower shapes still to be fully understood
  Rate capability sufficient for ILC environment
    No dead time > 0.3 ms observed
    Efficiency decreasing with rates above 100 Hz/cm^2

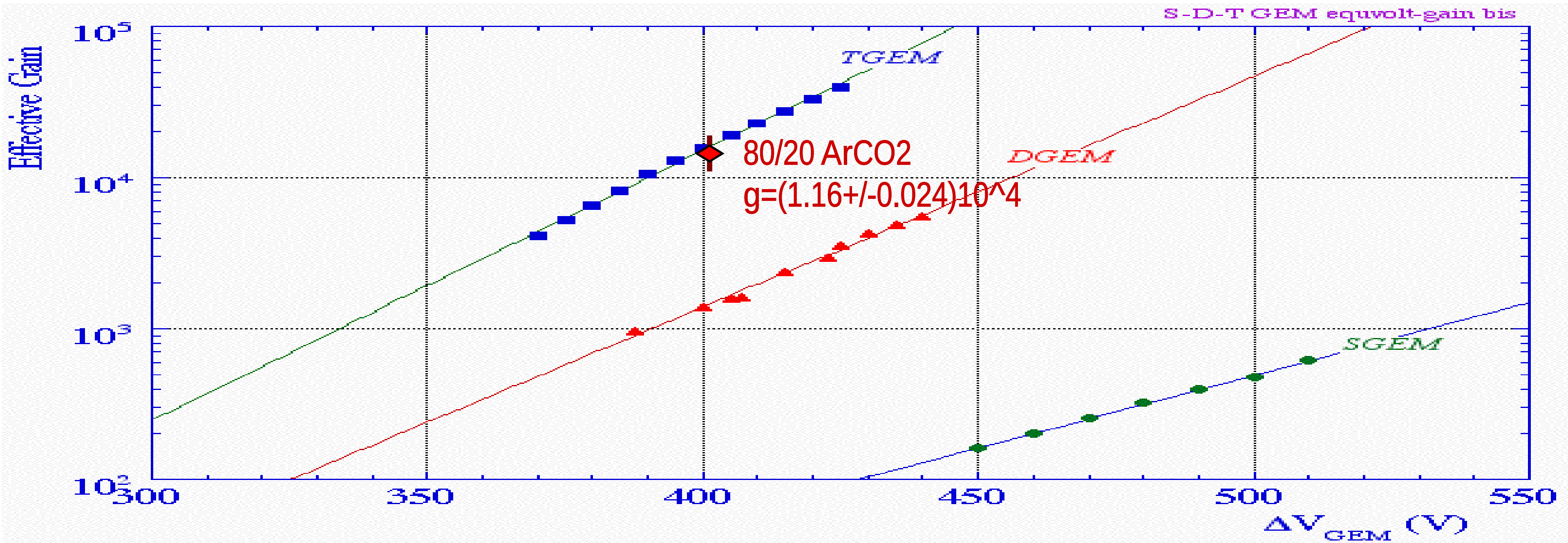
- **From long term tests (> 18 months) with Cosmic Rays**
  RPCs are reliable and stable

DHCAL

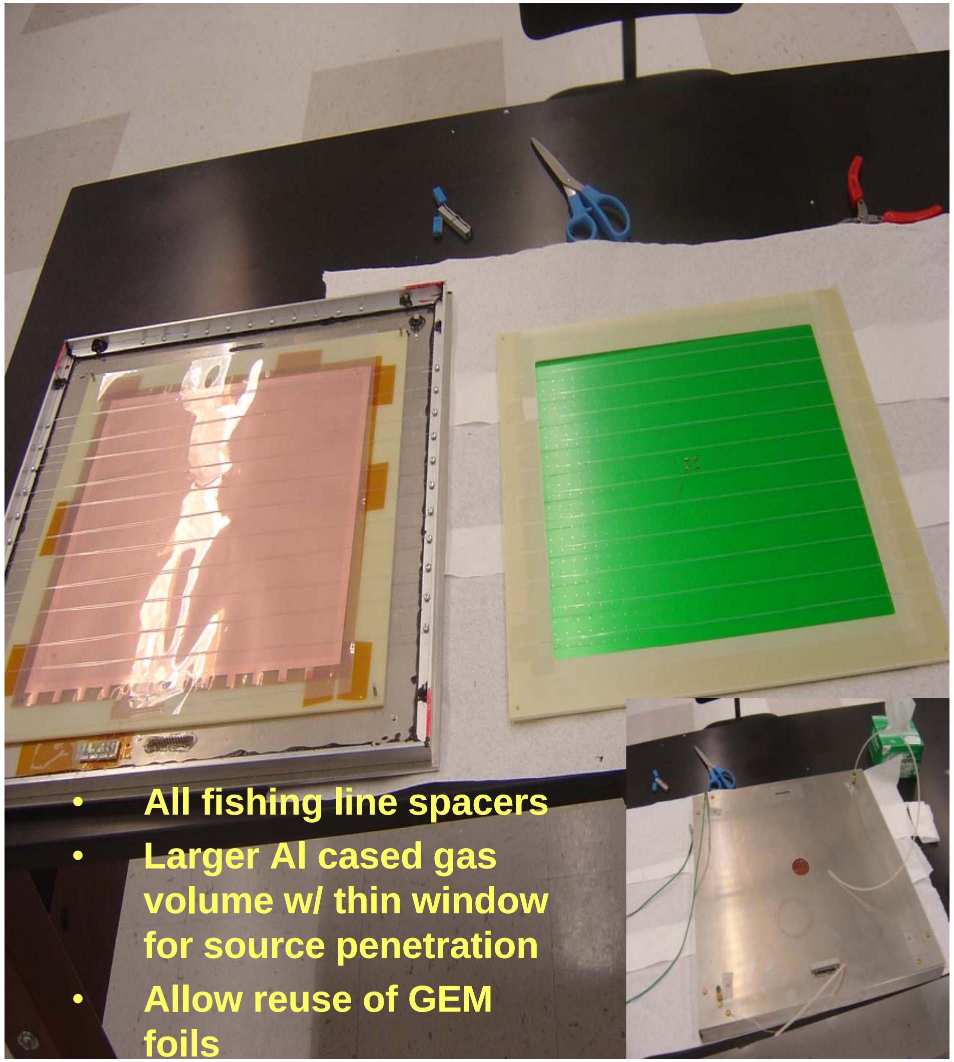
GEM would be a possible alternative
GEM Beam Test Detector Setup

GEM Chamber Absolute Efficiency and Gain

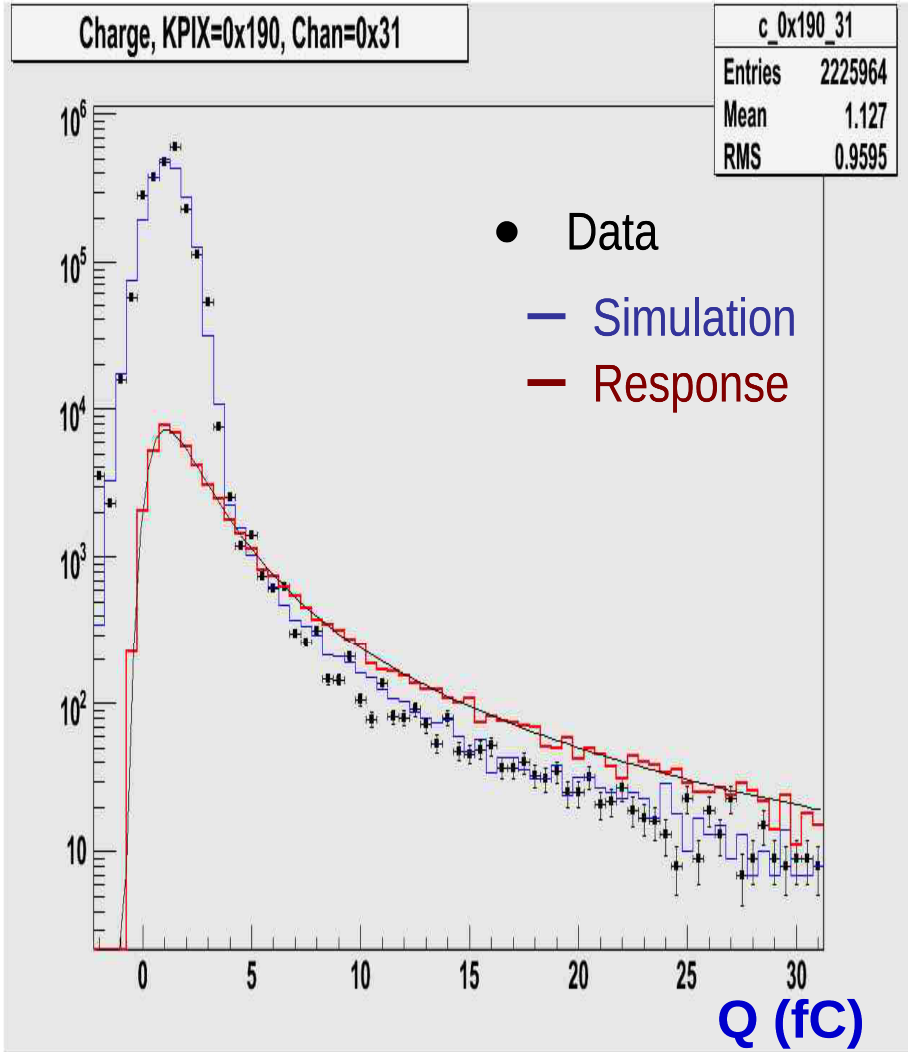




GEM-KPiX Readout and Responses



- All fishing line spacers
- Larger Al cased gas volume w/ thin window for source penetration
- Allow reuse of GEM foils



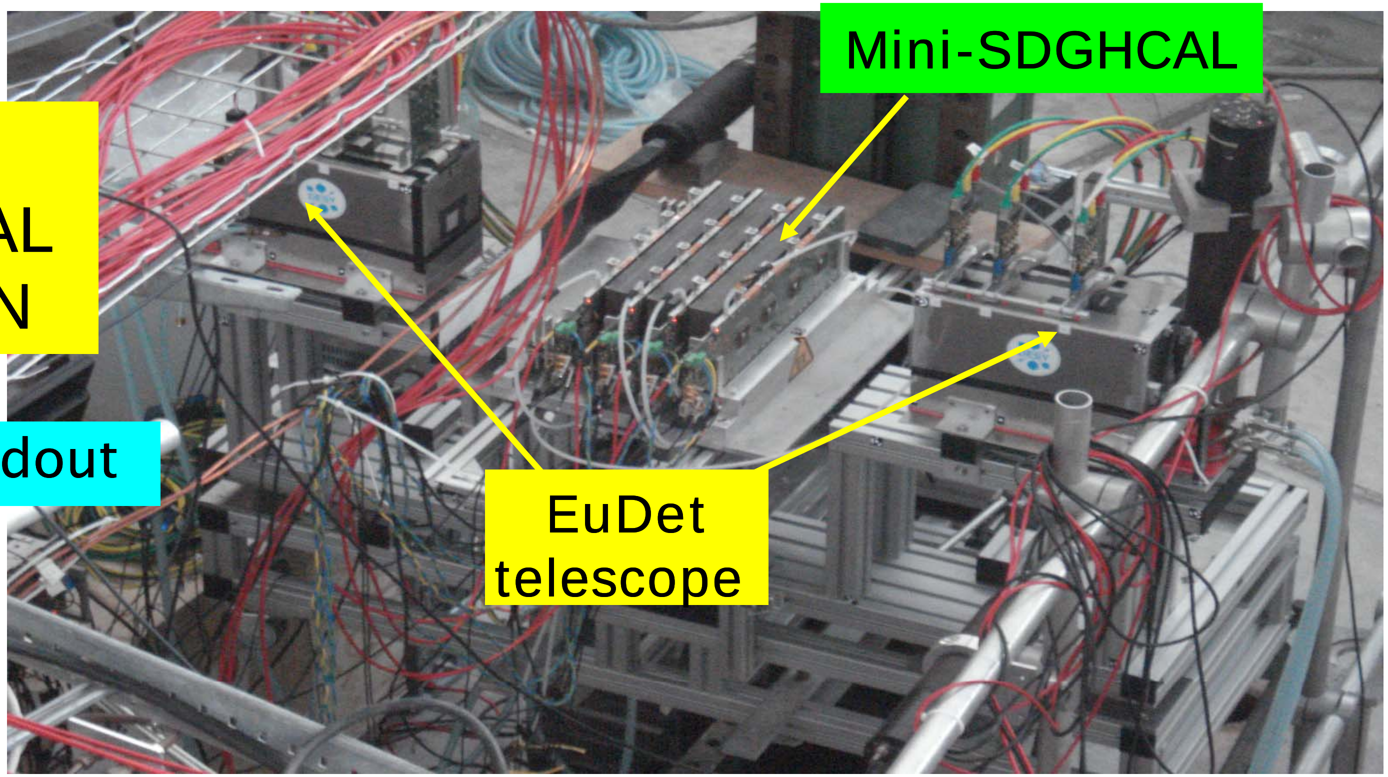
GEM DHCAL Summary and Plans

- Much progress made with 30cmx30cm GEM chambers
- GEM-KPiX readout integration in progress
  - Working with SLAC team for tests with next generation KPiX
  - Plan to integrate with ANL-FNAL developed DCAL
- 1mx33cm long foil development with CERN for 1mx1m unit chambers for large scale test
  - 3M Inc. punted on flex circuit division
  - Source, cosmic ray and beam test the chamber
  - Put them into CALICE HCAL beam test stack at FNAL
- Looking into large area TGEMs and RETGEM s for the future

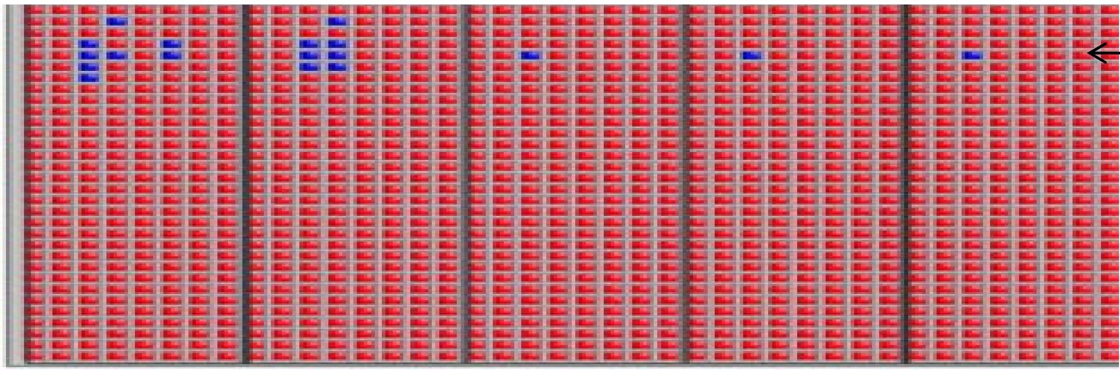
Semi-Digital Gas HCAL

Glass RPC
Mini-SDGHCAL
test at CERN

Semi-Digital readout



PS-CERN
(25th July – 7th August 2008)



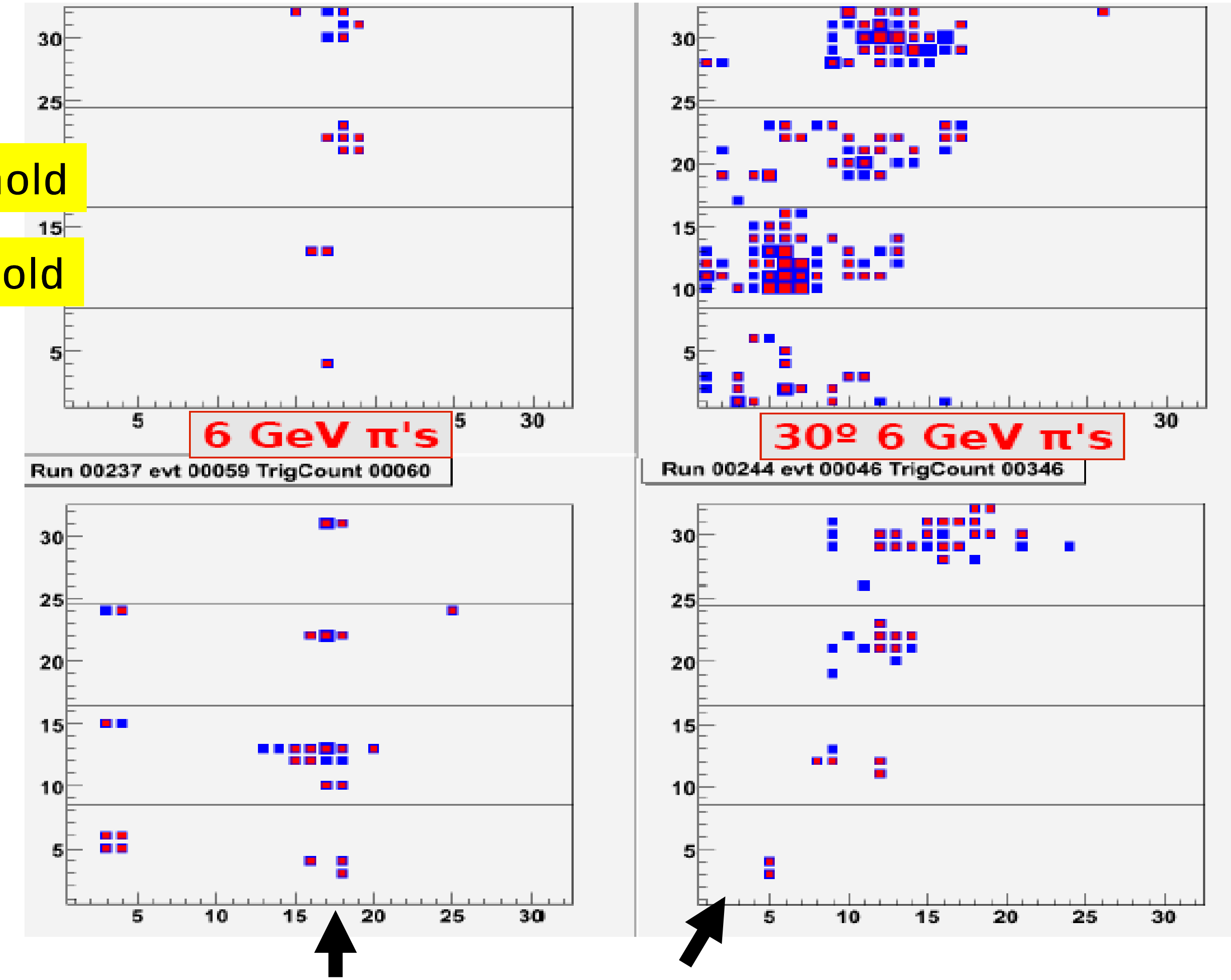
SDG-HCAL

Thanks to CERN SPS & PS team

Blue: 1st threshold

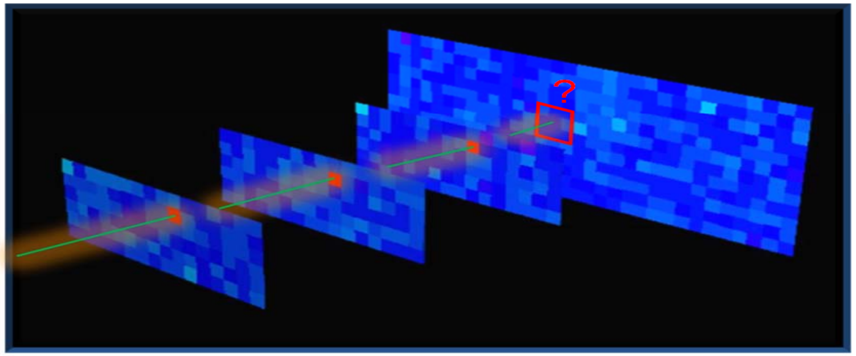
Red: 2d threshold

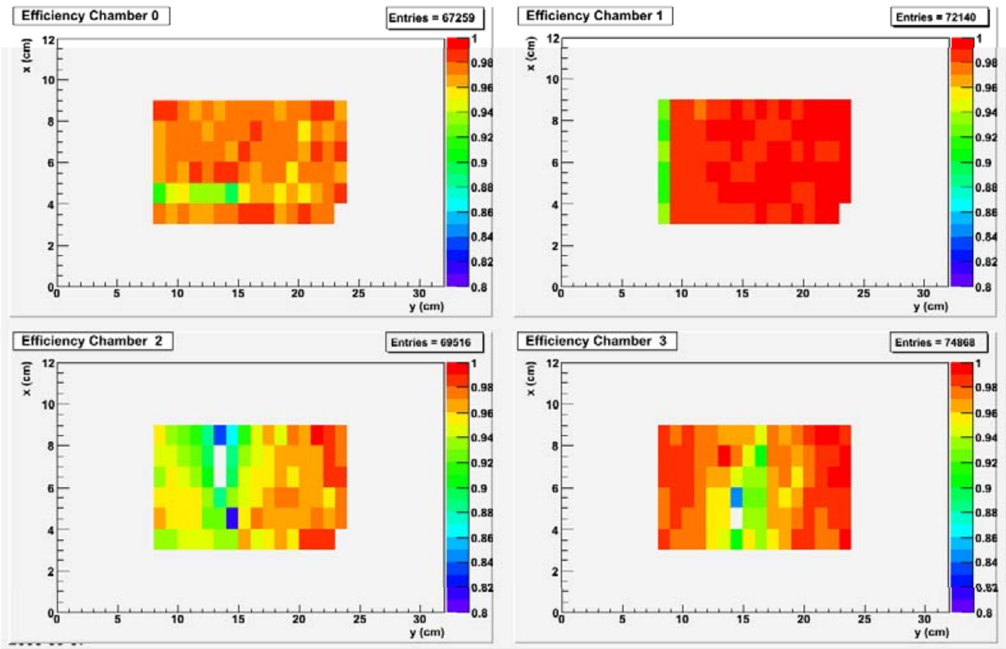
2cm Iron radiator

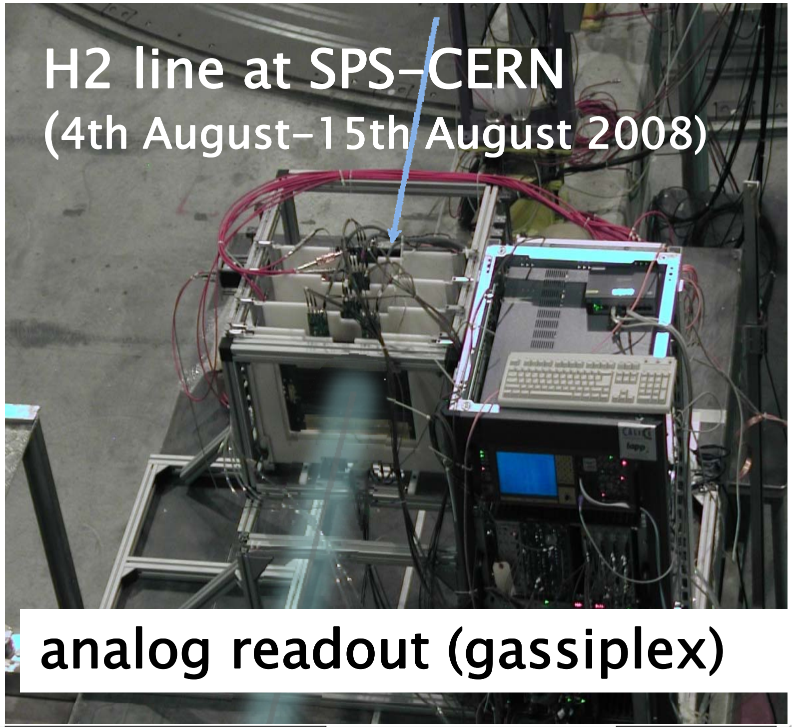


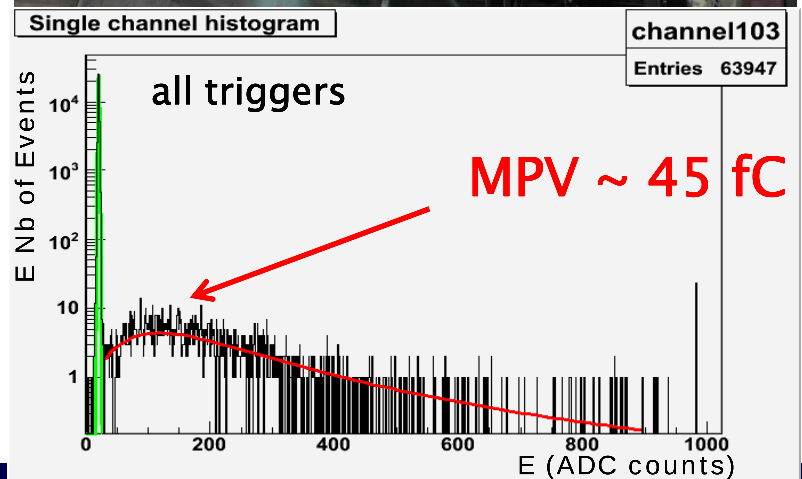
Beam (pions)

µMEGAS Mini-DHCAL test at CERN

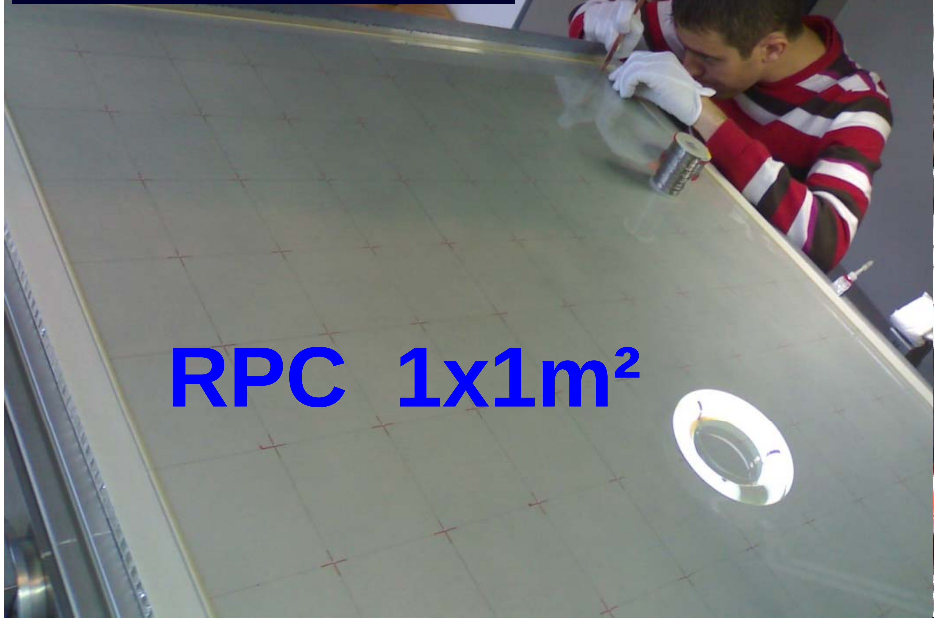


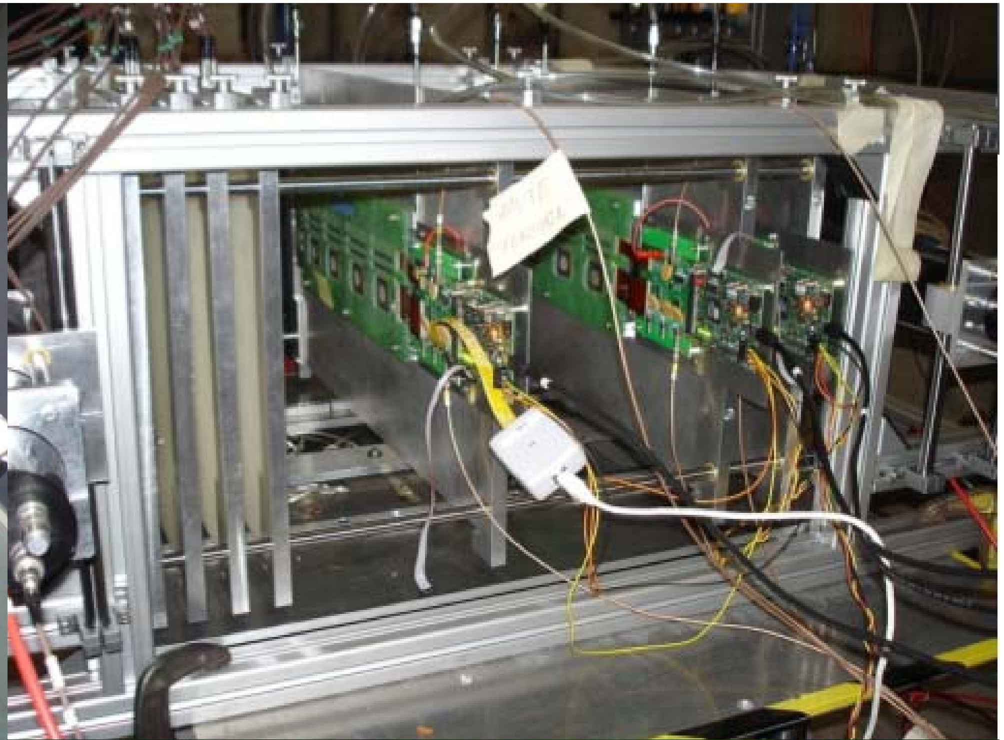


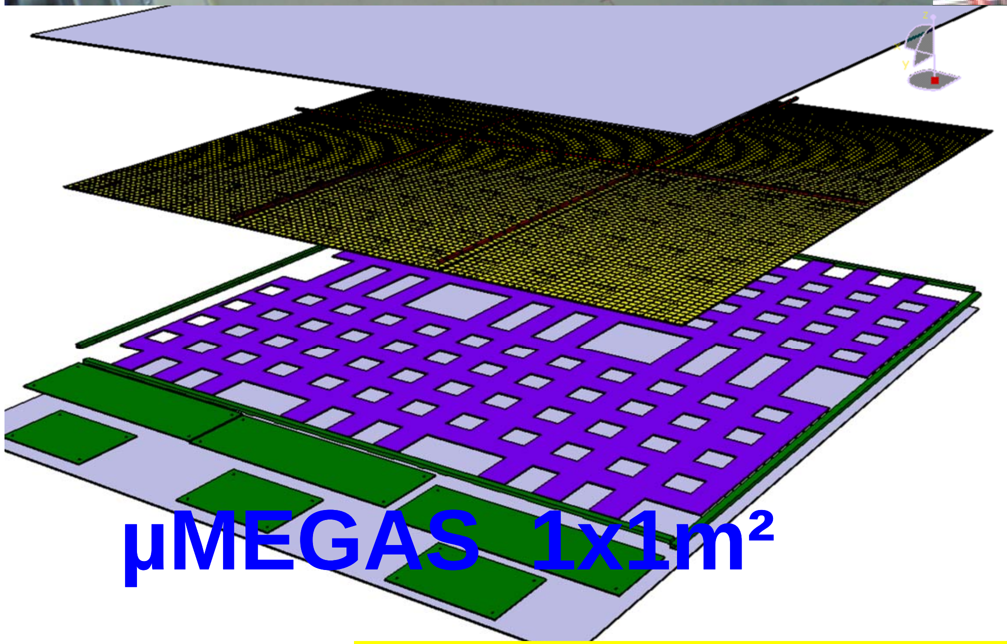




SDG-HCAL







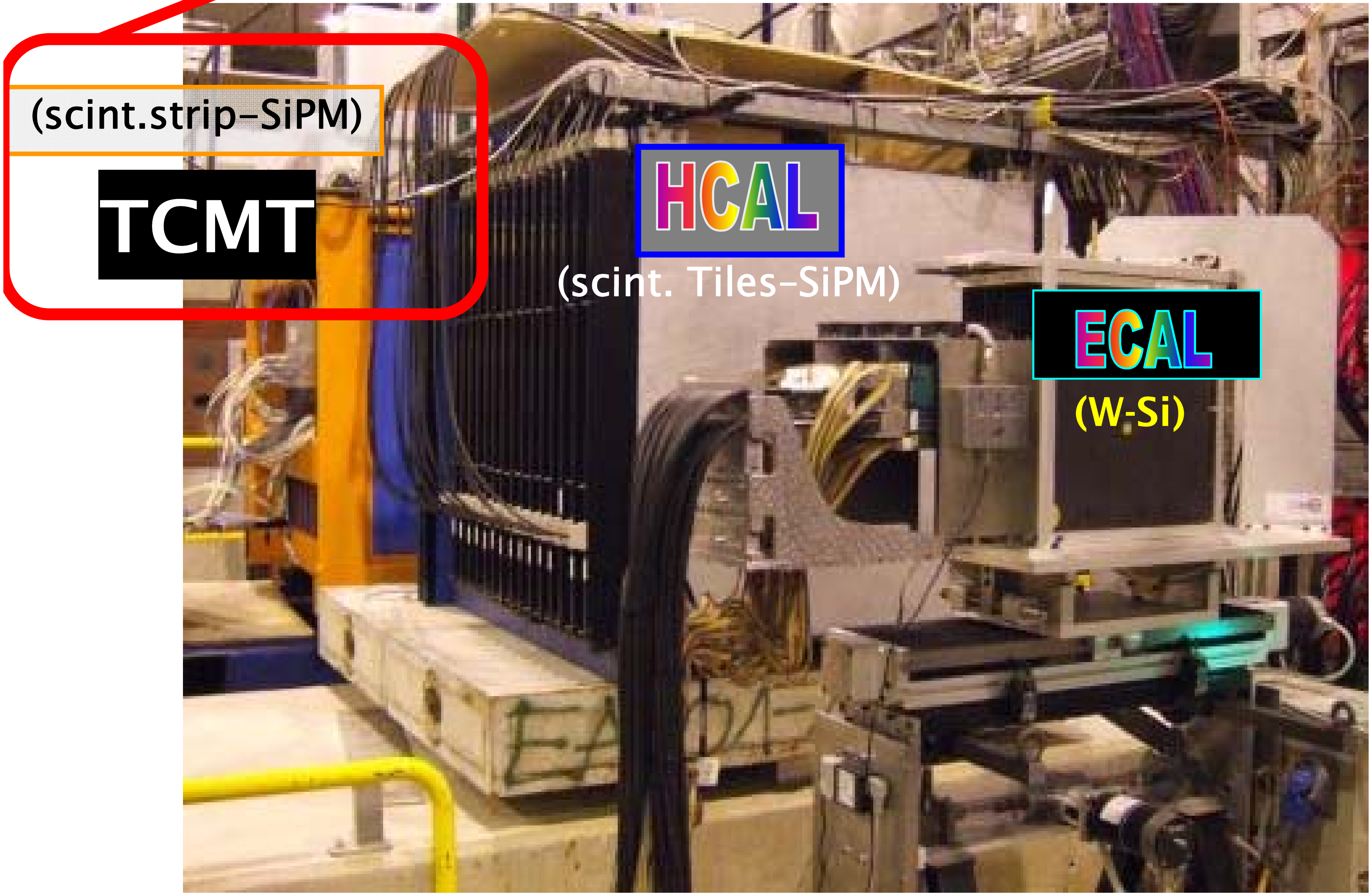
test of large area RPC & μMEGAS for SDGHcal in progress

SGDHCal next steps

- Preparation of $1m^2$ of RPC, MultiGapRPC, µMEGAS for test beam with embedded VFE chips

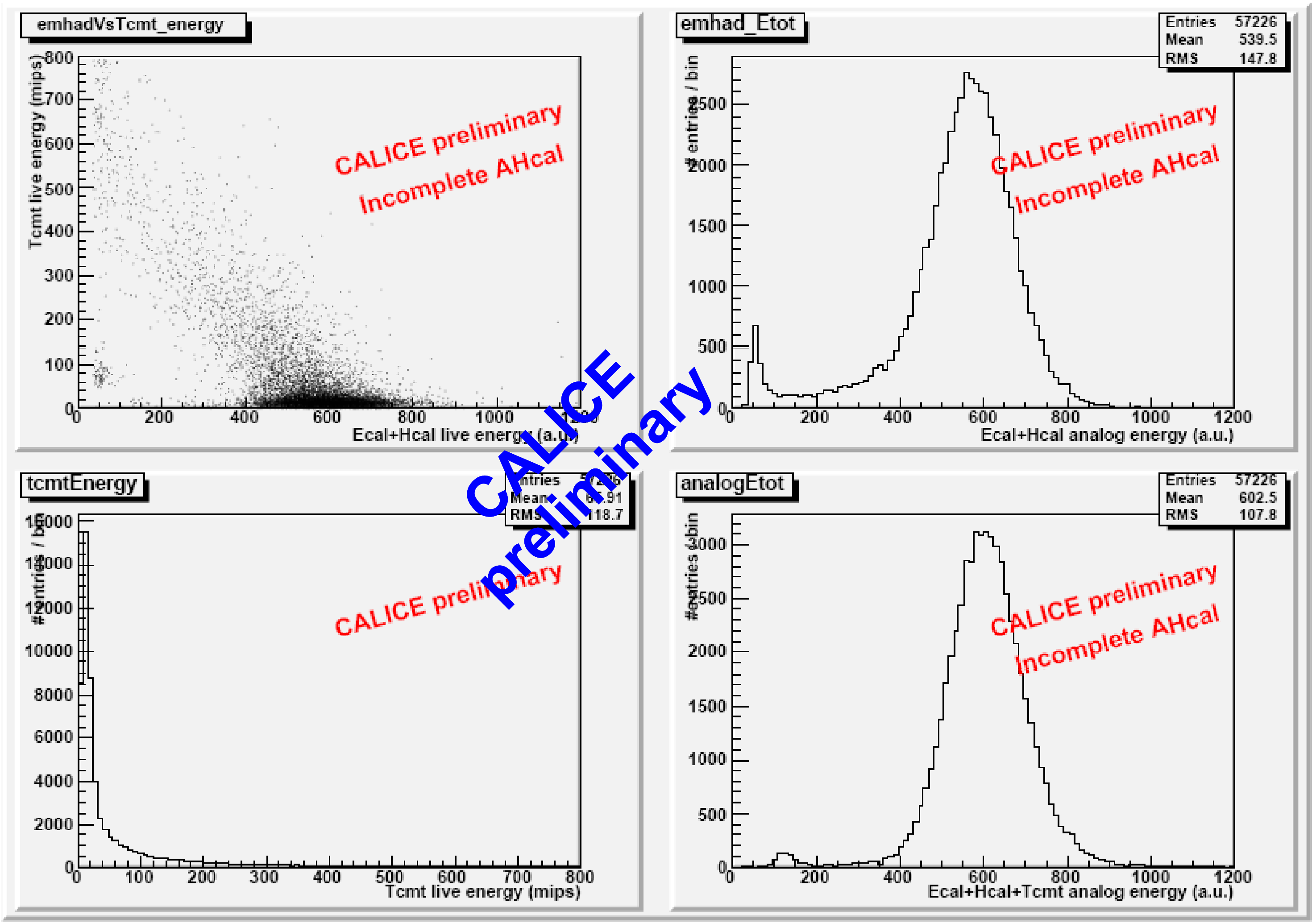
- Preparation of DAQ (FE, concentrator card, integration) and simulations for m^3

Test of muon tagger
+ tail catcher for Calo beam test



Analog Energy Response -20 GeV pion run – in TCMT

Scint. Strip
+
SiPM
Works nice



Using the 20 GeV pion run, the intra-component weights are found using the anti-correlation plots: ECAL vs AHCAL (not shown) and ECAL + HCAL vs TCMT (upper left)

And the technical R&D for all calo

- ECAL Tungsten – silicon
- ECAL Tungsten - scintillator strips
- ECAL Tungsten - MAPS

- HCAL scintillator Tiles
- HCAL digital RPC or GEM
- HCAL semidigital gas device (SDGHcal)
- TCMT : Scintillator/SiPM muon tagger

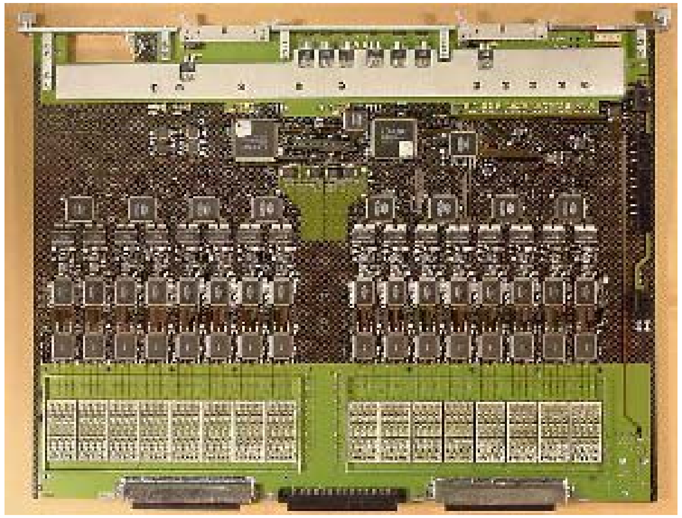
&

- VFE at high level of integration (an ATLAS readout board in a single chip)
- DAQ new generation (FPGA's and commercial board)
- GEANT4 simulation for prototype as well as for LOI detector model
- Analysis of the Test beam .i.e. Hadronic shower model tuning

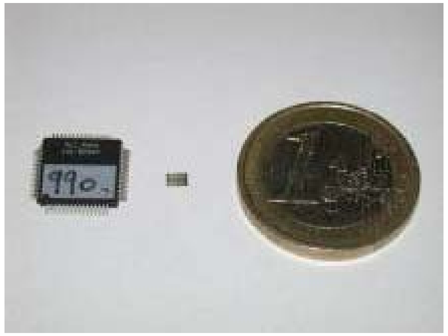
RESULTS in the domain of the electronics readout – 1

We learn to deal with very large numbers of channels and with ultra integrated chip

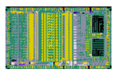
Please note the size in green and the power consumption in red



ATLAS LAr FEB 128ch 400x500mm 1 W/ch



FLC_PHY3 18ch 10x10mm 5mW/ch



64 channels
Few mm^2
ILC : <10μW/ch

Measured number

Tested with RPC NOW !!!

RESULTS in the domain of the electronics readout – 2

Most of the detector concepts propose to have the VFE inside !!
Never tested at the maximum of the shower and for HE electrons

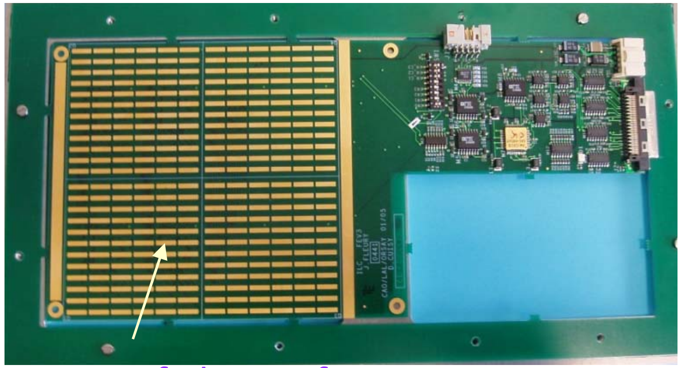
CERN test beam 100 GeV electrons

Shoot on the VFE chip at the maximum of the shower

Test of the behaviour of the VFE chip in high energy em shower

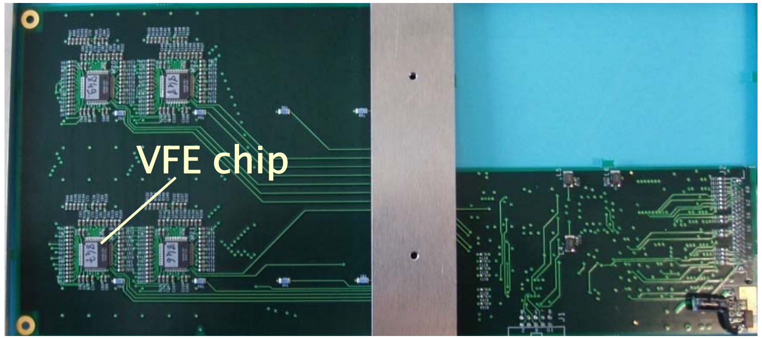
dedicated PCB with chip inside the detector

Front side



Location of silicon wafers

back side



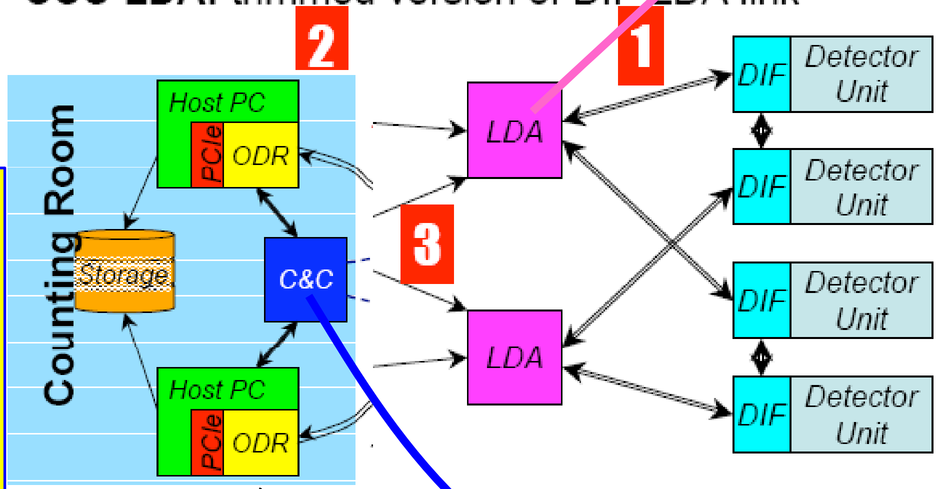
**The analysis of these data show
NO IMPACT on VFE from 100 GeV e.m. shower**

Beyond VFE

A DAQ for multi millions channels calo looks feasible

Links and protocols

1. **DIF-LDA:** 80-160 MHz serial link. 8b/10b encoded synchronous data transfers
2. **LDA-ODR:** Gbit ethernet (or possibly TLK2501) over optical fibre
3. **CCC-LDA:** trimmed version of DIF-LDA link



it is a very important step toward a full detector design

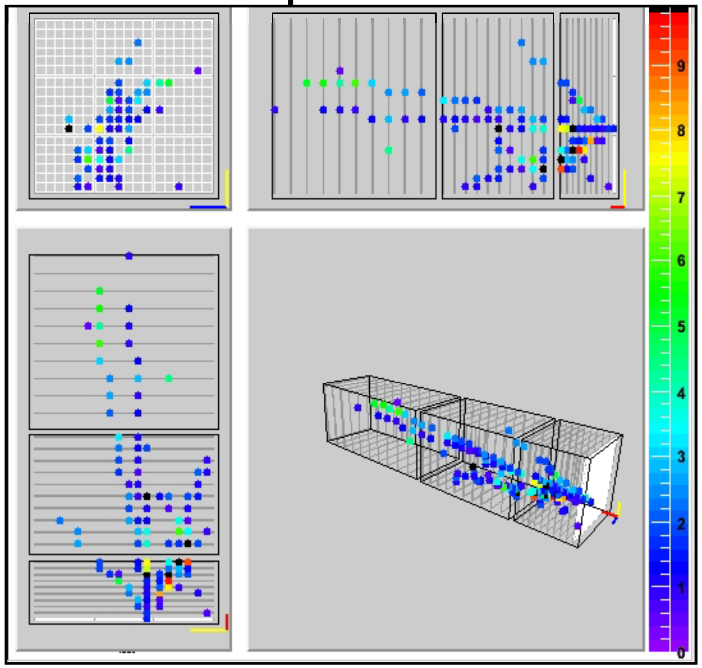
from the test beam at DESY,CERN and FNAL

- the detectors are robust and reliable
- ready for data few hours after installation

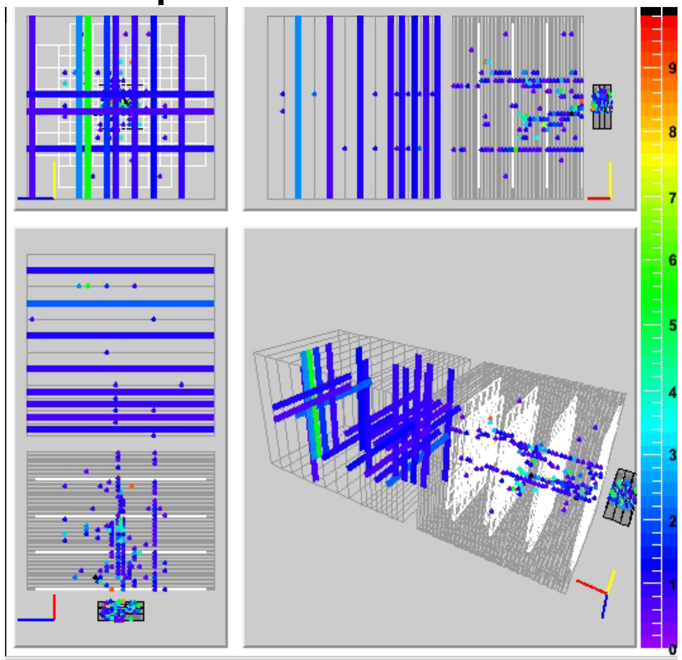
- We understand our detector, their advantages and drawbacks

- the TB data are nice to show !!! but it take time and manpower to analyse it

FNAL 8 GeV pion in ECAL W-Si



FNAL 8 GeV pion in HCAL Fe-Scint.



To summarize

1) First generation of ECAL and HCAL we are at the level of analysis of TB
Drawbacks and performances well understood (publications started)

2) Second generation of ECAL, HCAL, much closer to the final detector
After understanding of the pb saw in the first generation, we are building
Module of final detector with partial coverage (technical prototype)

From 1) and 2) , **We will be ready with 3-4 years to go to step 3**

3) Construction and test of a module zero (After LC construction decision)

To summarize

With the same level of support

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To finish

Our agenda

- STEP 1 analysed and published for 2010
- STEP 2 proto. built for 2010 , TB 2010-2012

- STEP 2 completed for 2012 - 2013
- READY for a module zero 2013

Thanks to (in order of contribution in this talk)
Roman Poeschl, Marcel Reinhard, Anne-Marie Magnan, Tohru Takeshita, Felix Sefkow , José Repond, Imad Laktineh, Vincent Boudry, Catherine Adloff, Remi Cornat , Valeria Bartsch and to
all collaborators of CALICE

To finish

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My personal message

With many contributions to CALOR08, with talks at ICHEP, TWEPP, etc..
CALICE has raised high the flag of ILC detector R&D in many conferences outside of ILC community .

Yes, there is a life beyond the "Black December"

Thanks to (in order of contribution in this talk)
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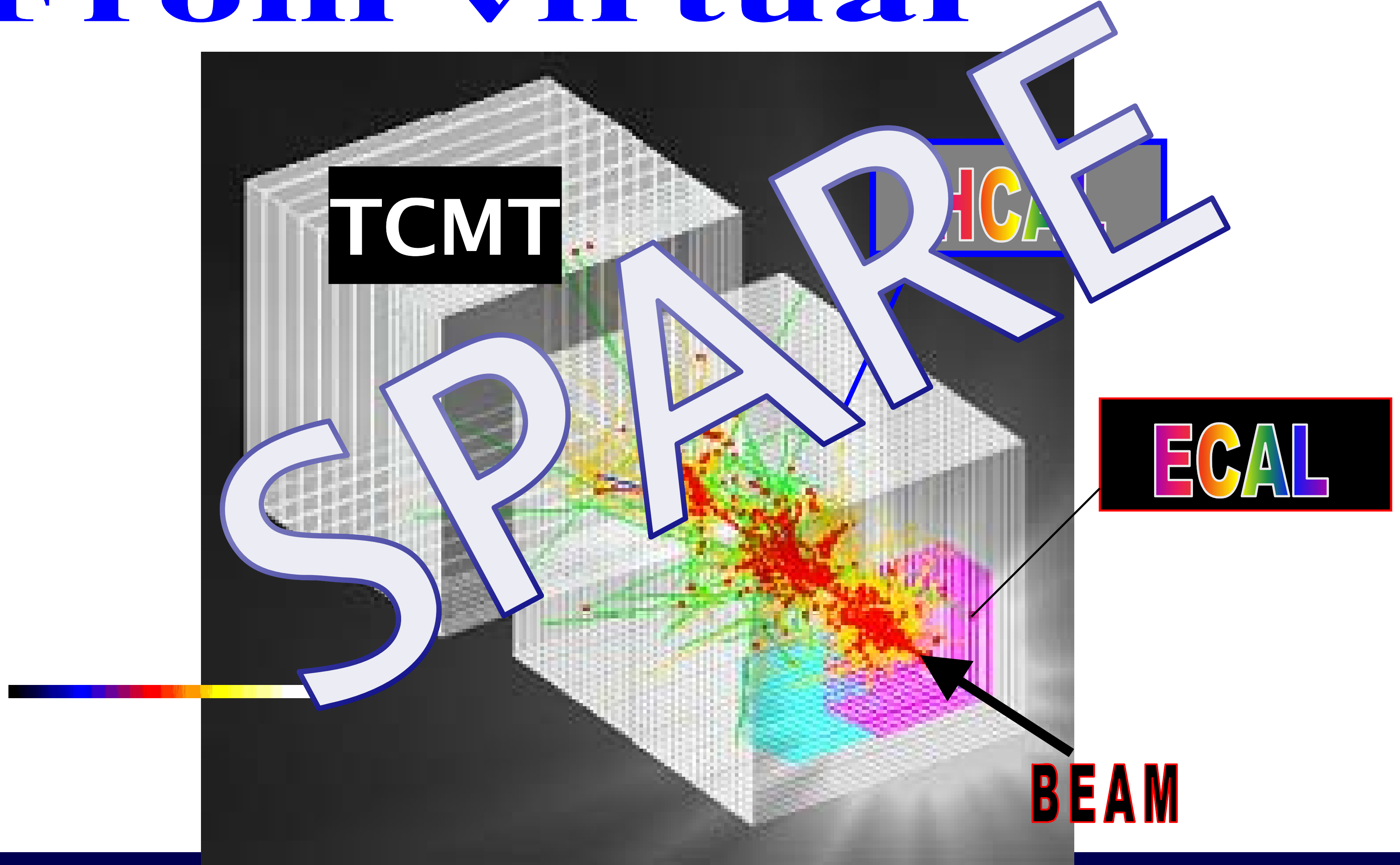
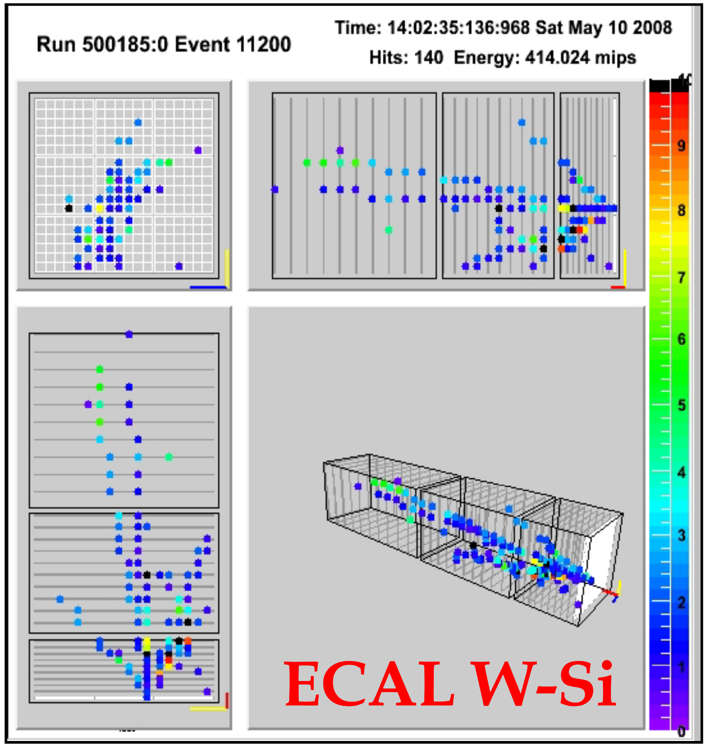
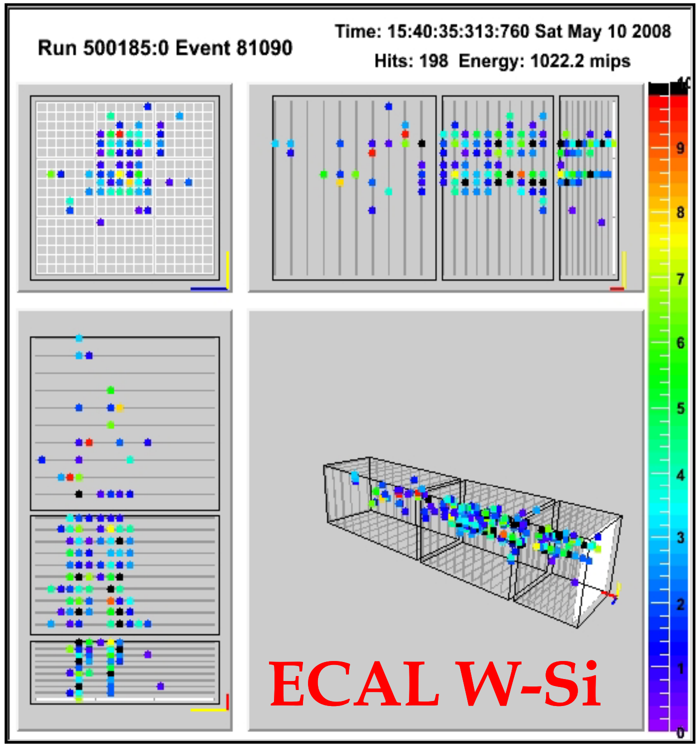
From virtual



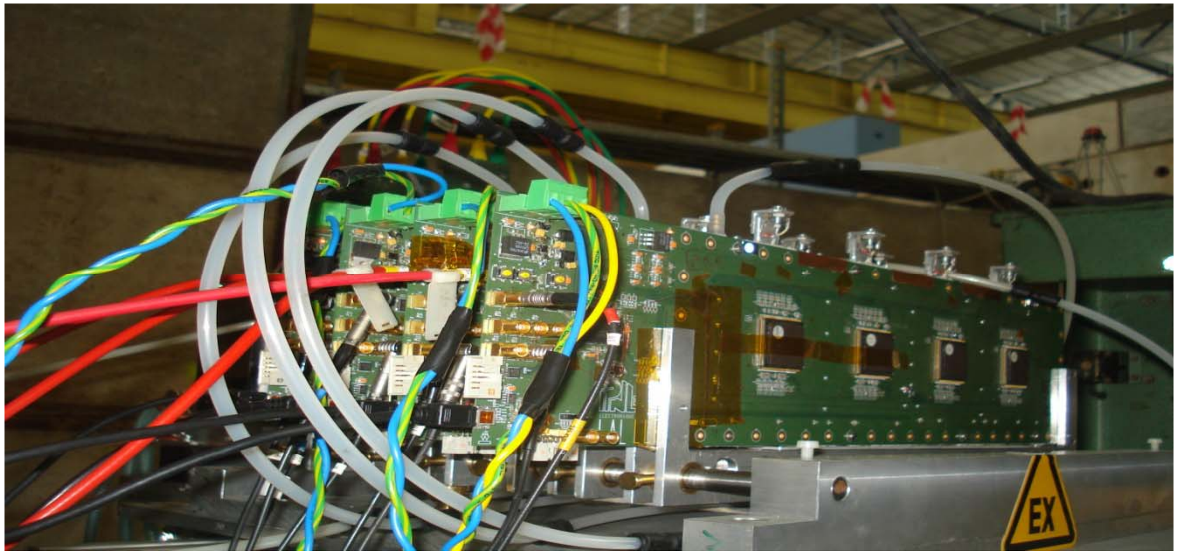
FNAL 8 GeV pion beam



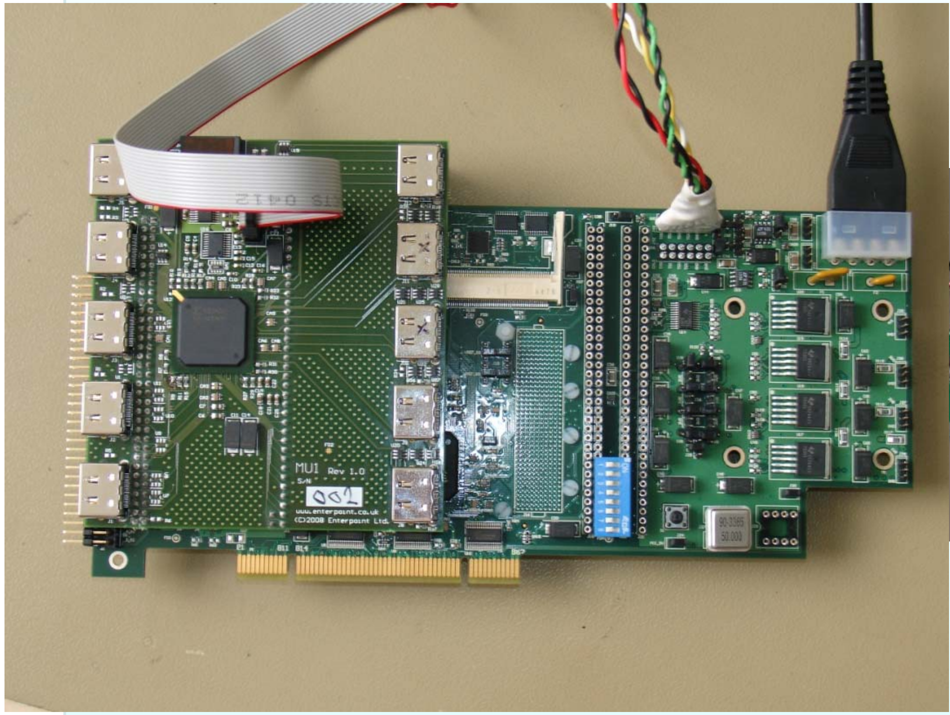


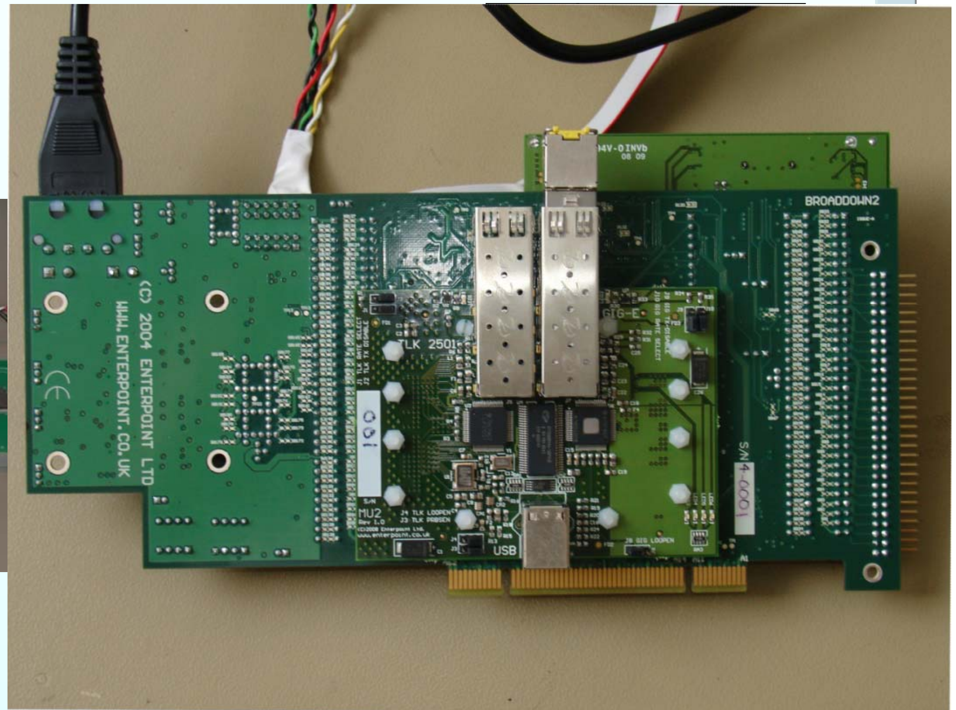
First study indicate that
1- software compensation would be feasible
2- Neutrons measurement could be done with time information vs E

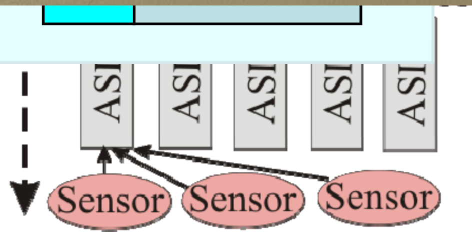
Hardware compensation is not the only way to have compensation


EX

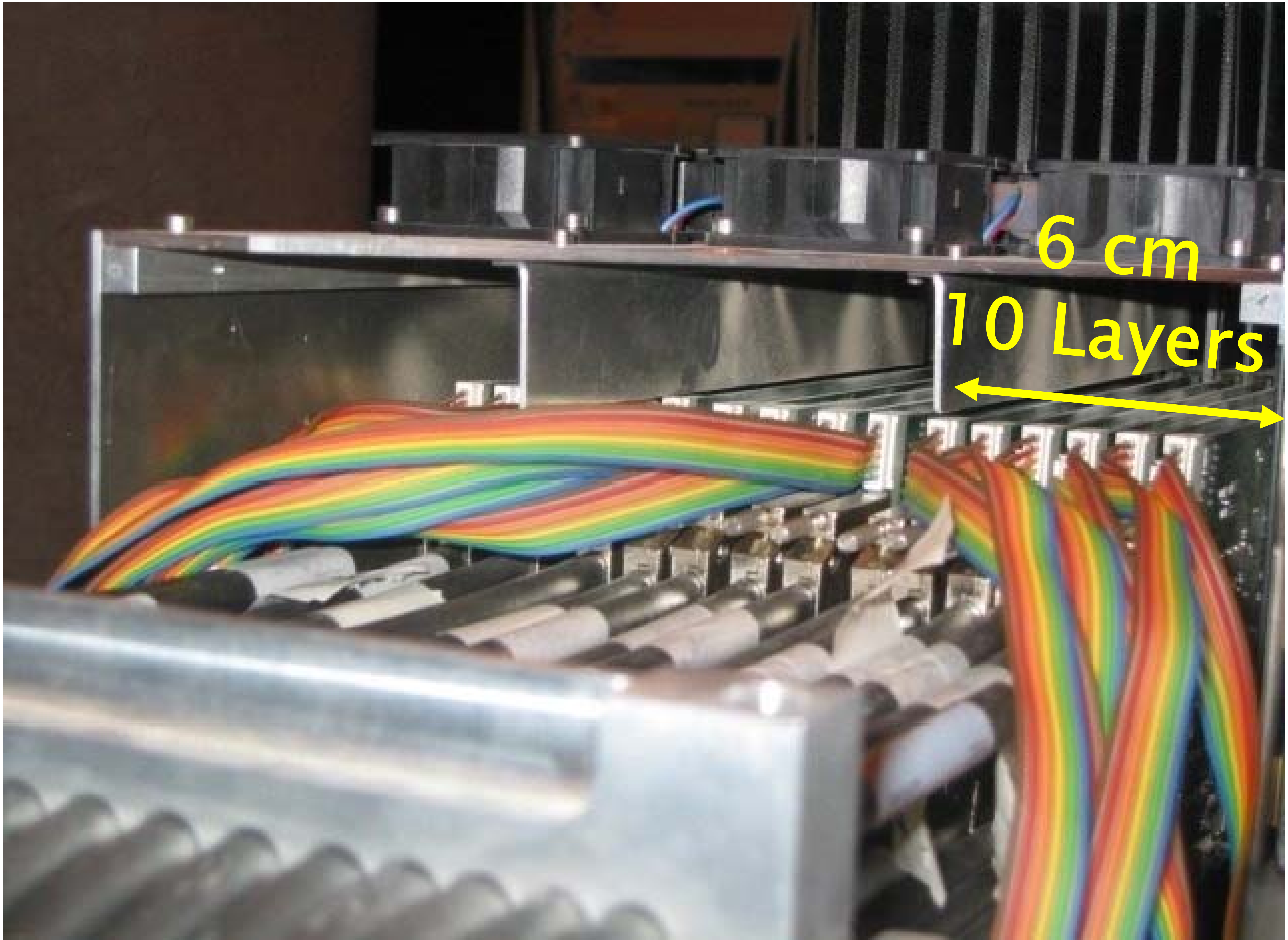
Next Generation DAQ







with some custom daughter boards


6 cm
10 Layers